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# ELEMENTS OF MINERALOGY, CRYSTALLOGRAPHY AND BLOWPIPE ANALYSIS

FROM A PRACTICAL STANDPOINT

INCLUDING

A DESCRIPTION OF ALL COMMON OR USEFUL MINERALS, THEIR  
FORMATION AND OCCURRENCE, THE TESTS NECESSARY FOR  
THEIR IDENTIFICATION, THE RECOGNITION AND MEAS-  
UREMENT OF THEIR CRYSTALS, AND THEIR  
ECONOMIC IMPORTANCE AND USES  
IN THE ARTS

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## PREFACE.

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In this, the fifth edition of our textbook, the "practical standpoint" of the former editions is maintained and skill in "Sight Recognition and Rapid Determination of Common and Economically Important Minerals" is still the chief objective.

About two hundred additional pages have been needed and the changes, while distributed, are principally:

(a) Descriptions of new economic groups and species consequent upon the great development in industrial applications.

(b) Discussions of formations and occurrences, in recognition of the growing interest in mineral genesis and of its value both in diagnosis and in connecting more closely geology and mineralogy.

(c) An enlarged section on crystallo-optics, schemes for crushed fragments and grouped optical distinctions consequent upon the proved value of the polarizing microscope in rapid mineral determinations.

(d) New tables for determination.

Two other new features may be mentioned:

1. In the introductory chapter, *as a substitute for the usual crystallographic course involving symbols and axes*, we have given a simplified method of classifying and identifying real crystals by *partial symmetry and angles* which enables the student after two or three lessons to recognize the crystalline system of real crystals and often to identify the species by simple measurements.

2. The gem minerals have been assembled and described in a separate chapter.



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# PART I.

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## CRYSTALLOGRAPHY.

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### CHAPTER I.

#### INTRODUCTORY.

The meaning of the word crystal in ancient times, and even in the English of the Middle Ages, was ice. Transparent, colorless quartz was called crystal because it was supposed to be ice in permanent form, the solids obtained on the evaporation of water were crystal, because like ice, they were solids formed from water.

#### **The Common Limited Meaning of Crystal.**

Both the quartz and the solid salts from solutions occurred in shapes bounded by plane surfaces, and as other substances both opaque and transparent possessed such shapes, by an extension of meaning crystal came to signify *a shape bounded by plane faces*, and more exactly, crystals, in this limited sense, are solids, formed only when a chemical element or a chemical compound solidifies, and bounded by plane faces at definite angles to each other which are characteristic of the substance.

#### **The Broader Meaning of Crystal.**

It is known now that this "polyhedral" shape is due to definite internal structure and that this structure is of such a nature that a "crystal" *always* shows the same physical characters\* in all parallel directions and, generally speaking, different characters in different directions.

\* For instance, crystals will often break in directions parallel to planes yielding solids absolutely constant in angles, they will transmit light or conduct heat or electricity with the same velocity along all *parallel* lines, but with different velocity along lines not parallel.

But solidified chemical substances consist, for the most part, of crowded aggregations of individuals with little or no trace of plane-faced boundaries. Every grain, nevertheless, possesses the perfect regular internal structure with the physical characters constant in parallel directions and varying in directions not parallel, and often in earlier stages of growth did possess the polyhedral shape until crowding obliterated it.

The broad definition of crystal must therefore include these individuals. That is, crystals are *distinct individual solids resulting from the solidification of a chemical substance and showing constancy of properties in parallel directions and varying properties in directions not parallel.*

*Under favorable conditions of free space, time and surroundings crystals will be bounded by plane surfaces at definite angles to each other and characteristic of the substance.*

#### **Crystallization.**

Crystallization is therefore that solidification of a chemical element or compound which results in individuals possessing a crystal structure. These individuals may be completely bounded by plane surfaces or partially bounded by plane surfaces, or may lack all plane boundaries. They are identical in essentials and there is no line of division in the non-essentials.

#### **GEOMETRICAL CRYSTALLOGRAPHY.\***

Crystallography is broadly divided into:

Geometrical or Morphological Crystallography.

Physical Crystallography.

Chemical Crystallography.

Of these this book considers only those portions of the first two which experience has proved to be most useful in the identification and description of minerals.

Geometrical crystallography considers the relations between the bounding faces.

In elementary work the principal tasks are determinations of "system," recognition of type symbols, approximate angle meas-

\* Geometrical Crystallography often receives an unmerited proportion of the time devoted to the study of crystals as a natural result of the fact that the geometrical relations were first studied.

urements, and, perhaps most important, interpretation of crystal descriptions.

In more advanced work the tasks are exact measurements of angles, projection and delineation, determination of indices and elements (axial angles and parameters) and calculation of theoretical angles from elements and indices.

### The Angles of Crystals.

In any crystal three sorts of angles exist:

1. Plane angles between "edges" (intersections of faces).
2. Dihedral or interfacial angles.
3. Polyhedral angles between three or more planes.

While all of these are characteristic the interfacial angles are most conveniently used.

Single crystals show only *salient* angles, *re-entrant* angles are common on twinned crystals.

### Law of Constancy of Interfacial Angles.

The angles of crystals of any one substance conform to the following law: *In all crystals of the same substance the angles between corresponding faces are constant.*

This law, the first to be announced, was gradually developed; for instance, Steno in 1669 announced that in rock crystal there was no variation of angle in spite of the variation in relative size of the faces. In 1704 Guglielmini stated that every salt had its peculiar crystals, the angles of which were constant.

Romé Delisle in 1783 measured and described over four hundred crystal forms and announced that in each species "the respective inclination of the faces to each other never varies."

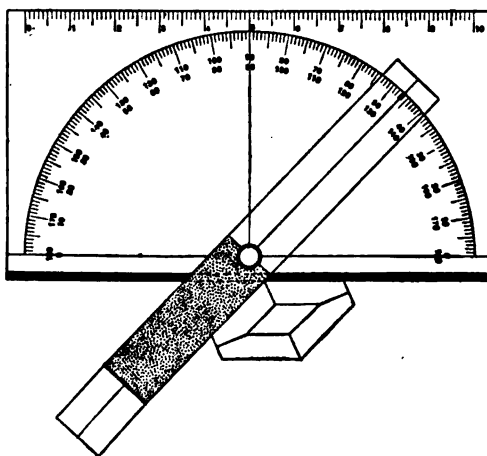
Aside from the crystals of the isometric system it is now held to be true that the crystals of each chemical substance *have a separate and definite set of angles*, certain so-called isomorphous substances crystallizing however with *very nearly* the same angles.

### Contact Goniometers.

Measurements within one or two degrees may be made with *Contact goniometers*, the most simple type of which consist of an arm pivoted upon a protractor. Fig. 1 shows Penfield Goniometer Model B, consisting of a cardboard on which is printed a semicircle graduated from  $0^{\circ}$  to  $180^{\circ}$  in both directions.

An arm of transparent celluloid is swivelled by means of an eyelet exactly in the center of the semicircle tightly enough to turn with some difficulty.

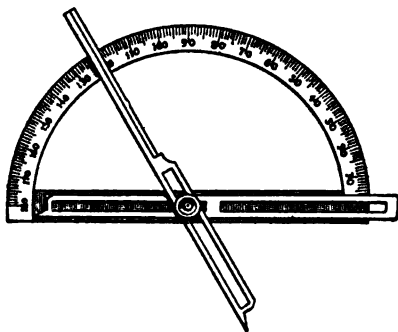
FIG. 1.



In measuring, the crystal or model is placed as shown so that the card edge and swinging arm are each perpendicular to the edge of intersection of the two faces, and in such close contact that no light passes between these and the faces. To facilitate this

one part of the swinging arm and the base edge of the card are blackened.

FIG. 2.



A more expensive instrument, Fig. 2, consists of a brass protractor with detachable arms which can be slid upon the pivot until of the most convenient length for the particular crystal.

In measuring the arms are detached and set at an angle a little less than the angle to be measured, clamped loosely and one of the arms placed in perfect contact with one crystal face. The other arm then nearly touches the second face and, while holding between the eye and the light, is brought into perfect

parallelism with the second face by a gentle pressure with the forefinger.

The arms are then replaced on the arc, as in the figure, and the angle is read.

#### THE APPROXIMATE MEASUREMENT OF INTERFACIAL ANGLES.

Determinations of symmetry, system, type symbols, and approximate angles, of sufficient accuracy to greatly help in the recognition of mineral species, can be made with very simple apparatus and even without apparatus.

In many cases the task is not so much to ascertain the value of the angles as to estimate the equality or inequality of different angles and the parallelism of faces to each other or to certain lines.

#### By Inspection Alone.

Estimates are best made by placing the two crystal faces concerned at right angles to a horizontal surface and tracing their intersections with the surface. The eye recognizes  $90^\circ$  with close approximation and fractional parts of  $90^\circ$  such as  $45^\circ$ ,  $30^\circ$ ,  $60^\circ$  with fair accuracy.

Parallelism of faces is judged by placing one of the faces in contact with a horizontal surface and noting the position taken by the other face. Parallelism between a face and a line is judged by placing a straight edge in different positions of contact with the face. If in any of the positions the straight edge and the line are parallel, the face and the line are also parallel. Parallelism of three or more faces to a common line is judged by the parallelism of the edges between the faces.

#### The Measuring.

A convenient order of measuring and recording is as follows:

A zone, or series of planes parallel to the same line, is selected which shows numerous or very well developed faces. This zone is placed with the faces vertical and a sketch made by tracing (or following approximately) these faces on the paper, giving for instance the outline *a, b, c, d, e, f, g, h*, Fig. 3. The edges between the oblique planes are then roughly sketched in and letters or numbers assigned to each oblique face.

Each angle of the vertical zone is then measured two or three

times, taking care to reset the goniometer after each reading. The average for each angle is then recorded. Usually the supplement angle, which can be read directly on Penfield Model B, is read and recorded, partly because the sum of all the supplement angles of a zone is  $360^\circ$ , partly because other angles are more simply checked or calculated and largely because crystallographic descriptions almost invariably record the supplement angles.

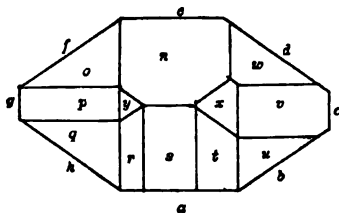


FIG. 3.

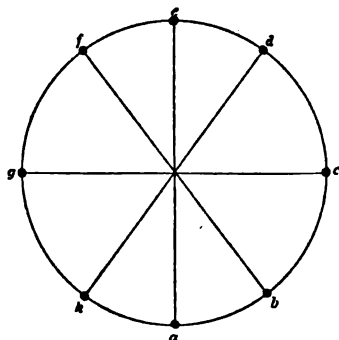


FIG. 4.

Any angle is conveniently designated by the symbols of the two faces, for instance, the angle between  $a$  and  $b$  by  $a \wedge b$ , the angle between  $t$  and  $x$  by  $t \wedge x$  and so on.

If the crystal is many-faced it may be convenient to also draw a circle and letting some point as  $c$ , Fig. 4, represent the face  $c$ , Fig. 3, lay off the supplement angles of that zone as arcs and draw the corresponding radii. By methods described later, p. 84, this drawing may be made to include the oblique faces. One advantage is that the unequal development of corresponding faces of a zone makes no change in the position of the "poles"  $a$ ,  $b$ ,  $c$ , etc., of Fig. 4. The "ideal" and the actual yield the same "poles." The angles between oblique faces or oblique and vertical faces are then measured.

All essentially equal angles are assembled and considered. Necessarily such an assemblage groups together angles between "equivalent" faces—it may also include angles between non-equivalent faces. Usually other facts will quickly separate these.

#### THE SYMMETRY OF CRYSTALS.

Although the angles between *corresponding* faces of all crystals of the same substance are equal, different crystals of the same

substance often show unequal numbers of faces, different angles and notably different shapes.

The property which such very different crystals of the same substance have in common is expressed by the following law:

### **The Law of Symmetry.**

*All crystals of any one substance are of the same grade of symmetry.*

Symmetry is fundamentally repetition. The sphere has infinite geometric symmetry. Every plane through the center divides it into symmetrical halves. Every diameter is an axis of infinite symmetry.

True geometric symmetry to lines and planes is rarely shown in the shapes of crystals. The actual symmetry is a symmetry in molecular structure (see page 26), a repetition *in different* directions of exactly the same arrangement. This shows in the crystal shape but as symmetry of direction with repetition of equal angles and not often as symmetry of position with repetition of equal-sized faces.

That is, there is in practically every crystal some repetition or recurrence of equal angles or similarly grouped faces, and two faces symmetrical *in this sense* may be unequally distant from the center, unequal in size and different in shape.\*

### **The "Elements" of Symmetry.**

It is customary to consider the symmetry of a crystal with reference to the center, axes, and planes, these being collectively known as "Elements of Symmetry."

### **Symmetry to the Center.**

Each face of the crystal has an opposite parallel face. Thus Fig. 5 represents a crystal of axinite with opposite parallel faces.

### **Symmetry to an Axis.**

When the crystal is revolved about some line through the center each group of faces is repeated 2, 3, 4, or 6 times during the revolution.

\* They will, however, be alike in lustre, markings and angles they make with planes or axes of symmetry.



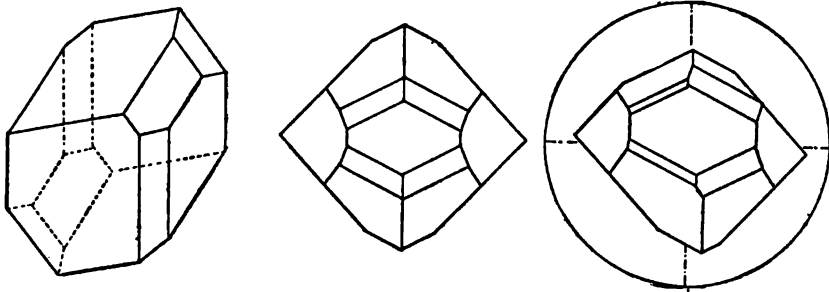
Thus in each of the orthographic projections, Figs. 6, 7, 8, 9, 10, there is an axis of symmetry perpendicular to the plane of the paper.

"Axes" of symmetry in crystals are rather directions than lines through specific points. Thus while in the topaz crystal of *ideal*

FIG. 5.

FIG. 6.

FIG. 7.



shape shown\* in Fig. 6 there is an axis of two-fold geometric symmetry *perpendicular to the plane of the page and through the center of the drawing*, the topaz crystal of Fig. 7 showing the same number of faces at the same angles has only symmetry of direction to an axis *perpendicular to the page*. Whether the axis is considered to be central or not is of no consequence.

Figs. 8, 9, 10 show respectively projections of calcite with a three-fold axis, zircon with a four-fold axis and beryl with a two-fold axis. The axis in each case is perpendicular to the plane of the page.

#### Finding an Axis of Symmetry.

Try any evidently prominent direction, place it in a vertical position. Note first whether there are any recurrent angles in the group of faces (if any) which are parallel to it; if not it cannot be an axis of symmetry. If there are recurrent angles in the zone of faces parallel to the direction note next the oblique faces and revolve, or imagine a revolution of, the entire crystal about the direction. Note the grouping of faces at any initial position. If during the revolution new groups of faces appear to

\* These drawings 6-10 are orthographic projections on a horizontal plane with one zone vertical. Parallel edges appear as parallel lines.

take positions *parallel* to the initial positions of all the faces the direction of rotation is a probable axis of symmetry. If, by measurement, the angles for one position correspond in value and order with those for the other position the existence of the symmetry axis is confirmed.

According to the number of times corresponding groups or faces recur during a complete revolution about a symmetry axis, the axis is known as two-fold, three-fold, four-fold, or six-fold. No other varieties exist.

FIG. 8.

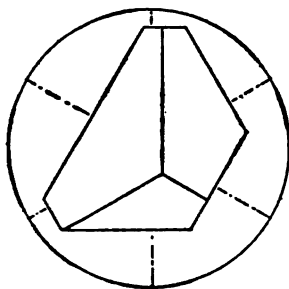


FIG. 9.

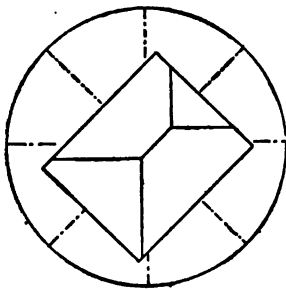
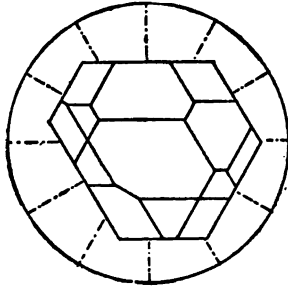


FIG. 10.



### Symmetry to a Plane.

A plane of symmetry holds a definite angular relation to a crystal rather than a fixed position *in* the crystal. So regarded it may be said that with respect to any plane of symmetry the crystal faces are in pairs and that the angle between each pair is bisected by the plane of symmetry, or that a plane of symmetry is so related to a crystal that on each side of that plane there will be grouped the same number of faces at the same angles to it and to each other and in the same order. Thus, not only in the model illustrated, Fig. 6, but in the crystals shown in Figs. 7, 8, 9, 10 there are planes of symmetry *parallel* to each of the dot and dash lines and each perpendicular to the plane of the paper.

### The Law of Symmetry therefore means:

That while the crystals of any one substance will not all be alike in shape even when the variations due to size and to unequal development of faces have been eliminated, there will be, in every crystal of the substance, wherever found or under whatever conditions formed, the same "Elements" of symmetry.

### Crystal Models and their Geometric Symmetry.

Models in which all equivalent faces are the same distance from the center, and therefore of equal size and the same shape, are much used in crystallography. It is desirable to restrict this use as the skill acquired in the study of models is of little use in the recognition of crystals.\* Fundamentally the problem is to recognize *directions of equivalent structure*. In the crystal such directions are indicated by faces symmetrical in *direction*, alike in markings, luster and relation to cleavage but of any size or shape, while in the model such directions are indicated by faces symmetrical in *position* and alike in size and shape.

A model is *symmetrical to the center* when every straight line through the center encounters at equal distances on each side of the center two corresponding points.

A model is *symmetrical to an axis* when if revolved about this axis the model reoccupies the same position in space, two, three, four, or six times during one complete revolution. That is, corresponding groups of planes exchange positions after revolutions of  $180^\circ$ ,  $120^\circ$ ,  $90^\circ$  or  $60^\circ$ .

FIG. 11.

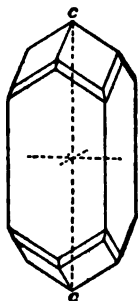


FIG. 12.

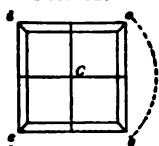


FIG. 13.

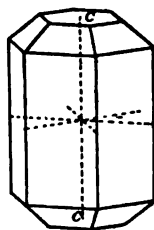
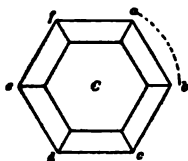


FIG. 14.



The line  $CC$  in the zircon crystal, Fig. 11, is an axis of *four-fold or tetragonal* symmetry, for, as shown in the horizontal projection, Fig. 12, the crystal occupies the same position in space when by rotation about  $CC$  any point  $a$  has moved to  $b$ ,  $c$ ,  $d$  or again to  $a$ , and does not for any other position.

\* Crystals are often spoken of in terms of models and said to be "distorted" when conforming perfectly to all known crystal laws but not resembling the model.

The line  $CC$  in the apatite crystal, Fig. 13, is an axis of *six-fold or hexagonal* symmetry, because, as shown in horizontal projection, Fig. 14, the crystal occupies the same position in space when by rotation about  $CC$  any point  $a$  has moved to  $b, c, d, e, f$  or again to  $a$ .

A model is *symmetrical to a plane* when the plane so divides it that either half is the mirrored reflection of the other, and every line perpendicular to the plane connects corresponding parts and is bisected by the plane of symmetry.

FIG. 15.

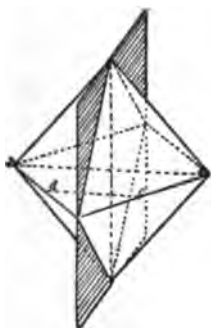
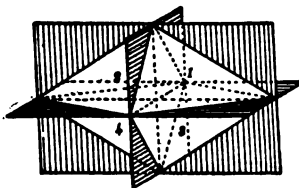


FIG. 16.



For example, in Fig. 15, the shaded plane so divides the model that a line from an angle  $b$  perpendicular to the plane passes through a corresponding angle  $a$ , or a perpendicular from  $c$ , the center of an edge, passes through  $d$ , the center of a similar edge.  $ab, cd$  and all similar lines are bisected by the shaded plane.

In Fig. 16 both of the shaded planes are planes of geometric symmetry for the model.

### Classification of Crystals.

The basis of classification is always, directly or indirectly, symmetry and profound investigations have proved that the crystal structure as limited by the law of simple mathematical ratio is of 32 types or classes. Nearly all the important minerals crystallize in ten or eleven of the thirty-two classes.

The six crystal "systems" constitute a more convenient classification. Each system includes two or more classes. Two methods of determining system will be described.

1. A method based on partial symmetry, which is very quickly and easily used for determining the systems of actual crystals and which supplemented by angle measurements will often determine the mineral.

2. A method based on crystal axes, but indirectly upon symmetry in the choice of crystal axes. This is indispensable in a mathematical consideration of the relations between faces and in the understanding of a crystal description.

#### CONSIDERATION OF CRYSTALS BY PARTIAL SYMMETRY AND APPROXIMATE ANGLES, WITHOUT SYMBOLS.

##### Rapid Method for Finding the System of a Crystal.

The following rules quickly determine the "system" of a crystal, without the need of a complete determination of symmetry or any consideration of "crystal" axes. They apply to all 32 classes except one.\*

Approximate measurements, as described p. 5, are usually needed.

| <i>Essential Condition.</i>  | <i>System.</i>                       |
|--|--------------------------------------|
| More than one axis of three-fold symmetry.   | Isometric.                           |
| One axis of four-fold symmetry, and one only.  | Tetragonal.                          |
| One axis of three-fold symmetry, and one only.   | Hexagonal.<br>Rhombohedral division. |
| One axis of six-fold symmetry.   | Hexagonal division.                  |
| More than one axis of two-fold symmetry but no axis of higher symmetry (or one axis and two planes of symmetry). | Orthorhombic.                        |
| One axis of two-fold symmetry only, or one plane of symmetry only, or both.                                      | Monoclinic.                          |
| Without axes or plane of symmetry.   | Triclinic.                           |

##### DISTINGUISHING SPECIES BY APPROXIMATE ANGLES.

Because the angles between *corresponding*† faces are constant and characteristic, the measuring of a few selected angles will often serve to determine the mineral. Certain angles are char-

\* The scalenohedral class of the tetragonal system by these rules would be orthorhombic.

† Corresponding faces on the same crystal, or on different crystals of the same substance, occupy corresponding or symmetrical positions with reference to the symmetry axes and usually correspond in lustre and markings. They frequently do not correspond in shape.

acteristic, others are common to many crystals, for instance, the angles between faces parallel to the four-fold axis in the tetragonal are possible angles for any substance crystallizing in the tetragonal system.

The "cleavage" directions are of great service in orienting the crystal. These and the angles between them are used in the lists which follow each system.

### ISOMETRIC SYSTEM.

#### Principal Characteristic.

If a crystal has more than one axis of three-fold symmetry it is an isometric crystal and not otherwise. It may or may not have three four-fold axes.

#### Prominent Features.

The bounding planes are often squares and equilateral triangles or these with their corners cut off. Corresponding faces and equal angles are more frequent than in other systems. Often the dimensions are closely equal in three or more directions.

#### Angles.

These are of the same "series" whatever the species. They are therefore classed by their "habit," that is, dominant "forms" on the crystals.

#### *Tetrahedral*, Fig. 17.

(Four faces at  $70^{\circ} 31'$ .) Sphalerite, tetrahedrite.

FIG. 17.

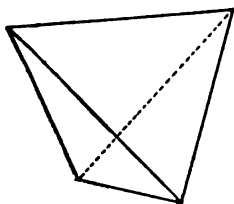


FIG. 18.

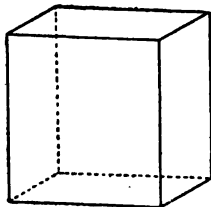
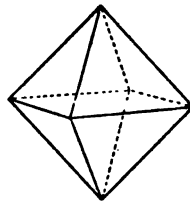


FIG. 19.



#### *Cubic*, Fig. 18.

(Six faces at  $90^{\circ}$ .) Argentite, cuprite, fluorite, galenite, halite, pyrite, smaltite.

#### *Octahedral*, Fig. 19.

(Eight faces at  $109^{\circ} 29'$ .) Chromite, cuprite, fluorite, franklinite, galenite, linnaeite, magnetite, pyrite, spinel.

*Dodecahedral*, Fig. 20.

(Twelve faces at  $120^\circ$ .) Cuprite, garnet, magnetite, sphalerite.

*Pyritohedral*, Fig. 21.

(Twelve faces often at  $126^\circ 53'$  and  $113^\circ 35'$ .) Cobaltite, pyrite, smaltite.

*Trapezohedral*, Fig. 22.

(Twenty-four faces often at  $131^\circ 19'$  and  $146^\circ 27'$ .) Analcite, garnet, leucite.

FIG. 20.

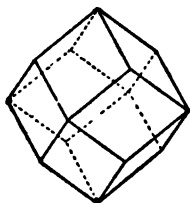


FIG. 21.

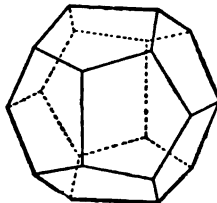
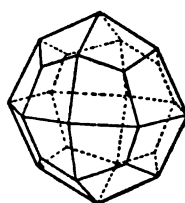


FIG. 22.



The following show notably good cleavages:

*Cubic.* Galenite, halite.

*Octahedral.* Fluorite.

*Dodecahedral.* Sphalerite.

## TETRAGONAL SYSTEM.

**Principal Characteristic.\***

If the crystal shows one axis of four-fold symmetry and only one it is a tetragonal crystal.

**Prominent Features.**

A section taken at right angles to the four-fold axis is usually square or octagonal, that is with angles of  $90^\circ$  or  $135^\circ$  between adjacent faces.

The dimension in direction of the four-fold axis is usually notably greater or less than in directions at right angles thereto.

**Angles.**

In the zone of the four-fold axis (faces *a*, *m*, Fig. 23) there are no variations in angle dependent on the species. All show the same series of angles and between corresponding faces these are principally  $90^\circ$ , more rarely  $143^\circ 8'$ .

\* see footnote p. 12

In all other zones the angles vary with the species.

Those important tetragonal minerals which often show macroscopic crystals may be classified by angles and cleavage as follows:

ANGLES BETWEEN CORRESPONDING FACES OBLIQUE TO THE  
FOUR-FOLD AXIS.

|                       |   |
|-----------------------|---|
| 71° 20' chalcopyrite. | 121° 41' cassiterite.                     |
| 99° 38' wulfenite.    | 123° 8' rutile ( $p \wedge p$ , Fig. 23). |
| 100° 5' scheelite.    | 123° 19' zircon.                          |
| 105° apophyllite.     | 129° 21' vesuvianite.                     |
| 109° 53' braunite.    | 136° 15' wernerite.                       |

Braunite, scheelite and wulfenite cleave at the angles mentioned.

Wernerite and rutile cleave parallel the four-fold axis giving angles of 90° and 135°. Apophyllite cleaves to cubic forms, but in one direction much more easily than in the other two.

FIG. 23.

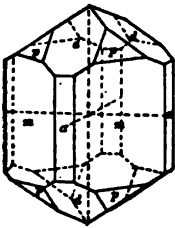


FIG. 24.

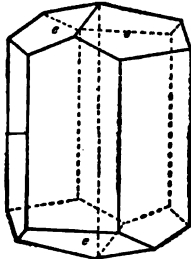
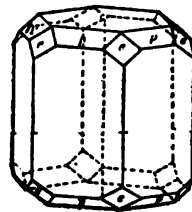


FIG. 25.



HEXAGONAL CRYSTALS.

Principal Characteristic.

If the crystal shows one and only one axis of three-fold symmetry it is a hexagonal crystal, rhombohedral division.

If the crystal shows one and only one axis of six-fold symmetry it is a hexagonal crystal, hexagonal division.

Prominent Features.

A section taken at right angles to the axis of three-fold or six-fold symmetry is usually a hexagon or twelve-sided, that is with angles of 120° or 150° or in some minerals an equilateral triangle with the corners "modified."

The dimension parallel this axis is usually notably greater



(prismatic crystals) or less (tabular crystals) than the dimensions at right angles thereto.

### Angles.

In the zone of the three-fold axis, Fig. 24, or six-fold axis, Fig. 25, there are no variations in angle dependent on the species. All show the same series of angles and between corresponding faces these are principally  $120^\circ$  or larger such as  $141^\circ 47'$  the occurrence of which tends to produce a nearly circular cross section.

In all other zones the angles vary with the species.

The important hexagonal minerals, which occur frequently in macroscopic crystals, may be classified by angles and cleavage as follows:

#### I. WITH AXIS OF THREE-FOLD SYMMETRY (USUALLY RHOMBOHEDRAL HABIT).

(a) Angles are both interfacial and cleavage:

$85^\circ 14'$  chabazite.

$86^\circ$  hematite.

$105^\circ 5'$  calcite.

$106^\circ 15'$  dolomite.

$107^\circ$  rhodochrosite.

$107^\circ$  siderite.

$107^\circ 24'$  magnesite.

$107^\circ 40'$  smithsonite.

$107^\circ 58'$  proustite.

(b) Angles interfacial only:

$85^\circ 31'$  ilmenite.

$90^\circ 50'$  alunite.

$92^\circ 37'$  willemite.

$116^\circ 36'$  phenacite.

$133^\circ 8'$  or  $103^\circ$  tourmaline.

#### II. WITH APPARENT AXIS OF SIX-FOLD SYMMETRY (USUALLY PRISMATIC HABIT).

(c) Often capped by horizontal plane:

Beryl nephelite.

Iodyrite pyrrargyrite.

Mimetite pyromorphite.

Vanadinite.

(d) Often capped by oblique planes:

$86^\circ 4'$  or  $128^\circ 2'$  corundum.

$94^\circ 14'$  or  $133^\circ 44'$  quartz.

$142^\circ 15'$  apatite.

(e) *Tabular*: graphite, molybdenite, iridosmine.

### ORTHORHOMBIC CRYSTALS.

#### Principal Characteristic.

If a crystal shows either more than one axis of two-fold symmetry (or one axis with more than one plane of symmetry) and nothing of higher symmetry it belongs to the orthorhombic system.

#### Prominent Features.

Cross sections taken at right angles to the axes of symmetry are unlike in angles and tend to rectangles and rhombs or these combined.

#### Angles.

There is no zone which has a constant series of angles for all species. The interfacial angles in the zones parallel to the axes of symmetry are unlike except when  $90^\circ$  and vary with the species.

Because the three axes of symmetry are all two-fold no practicable method exists for distinguishing between them. If, however, in any crystal angles are found that correspond to important angles in the zones of at least two such axes, for any species, the crystal is probably of that species.

In the table the columns *A*, *B*, *C* give prominent angles in zones parallel to the three symmetry axes. Other prominent angles are assembled in *D*. Thus in Fig. 26, the symmetry axes being shown by dotted lines, in the zone of the vertical axis the angle  $m \wedge m$  is  $129^\circ 31'$ , in the zone of the axis from front to back  $d \wedge d$  is  $119^\circ 46'$ . No angles occur in the zone of the axis from left to right, and finally such an angle as  $p \wedge p = 139^\circ 53'$  is evidently prominent. These are found in the columns *C*, *A* and *D* respectively under chrysoberyl.

The important orthorhombic minerals which frequently occur in macroscopic crystals may be classified as follows:

\* = bisected by cleavage.

† = parallel cleavage.

|                   | <i>C</i>                | <i>B</i>        | <i>A</i>        | <i>D</i>           |
|-------------------|-------------------------|-----------------|-----------------|--------------------|
| Stibnite.....     | $90^\circ 26' *$        |                 |                 | $108^\circ 36'$    |
| Andalusite.....   | $90^\circ 48' \dagger$  |                 | $190^\circ 50'$ |                    |
| Natrolite.....    | $91^\circ 15'$          | rare            | rare            | $142^\circ 23'$    |
| Sillimanite.....  | $91^\circ 45' *$        | none            | none            | none               |
| Goethite.....     | $94^\circ 52' *$        | $113^\circ 6'$  | $117^\circ 30'$ |                    |
| Enargite.....     | $97^\circ 53' \dagger$  |                 |                 |                    |
| Manganite.....    | $99^\circ 40' *$        | $114^\circ 19'$ | $122^\circ 50'$ |                    |
| Brookite.....     | $99^\circ 50'$          | rare            | rare            | $101^\circ 31'$    |
| Columbite.....    | $100^\circ 43'$         | $140^\circ 37'$ | $96^\circ 51'$  | $90^\circ \dagger$ |
| Barite.....       | $101^\circ 38' \dagger$ | $102^\circ 17'$ | $74^\circ 34'$  | $90^\circ \dagger$ |
| Sulphur.....      | $101^\circ 46'$         | $46^\circ 16'$  | $55^\circ 26'$  | $106^\circ 26'$    |
| Anglesite.....    | $103^\circ 44' \dagger$ | $101^\circ 13'$ | $75^\circ 36'$  | $90^\circ$         |
| Calamine.....     | $103^\circ 51' \dagger$ |                 |                 |                    |
| Celestite.....    | $104^\circ 10' \dagger$ | $101^\circ 11'$ | $76^\circ$      | $90^\circ \dagger$ |
| Marcasite.....    | $105^\circ 5'$          | $63^\circ 40'$  | $78^\circ 2'$   |                    |
| Arsenopyrite..... | $112^\circ 27' \dagger$ | $56^\circ 57'$  | $78^\circ 5'$   |                    |
| Aragonite.....    | $116^\circ 12' \dagger$ |                 | $108^\circ 27'$ |                    |
| Cerussite.....    | $117^\circ 14' \dagger$ |                 | $108^\circ 16'$ |                    |
| Topaz.....        | $124^\circ 17'$         | $57^\circ 59'$  | $55^\circ 19'$  | $141^\circ$        |
| Staurolite.....   | $129^\circ 20' *$       | $69^\circ 28'$  | $90^\circ$      |                    |
| Chrysoberyl.....  | $129^\circ 31'$         |                 | $119^\circ 46'$ | $139^\circ 53'$    |

### MONOCLINIC CRYSTALS.

#### Principal Characteristic.

If a crystal shows one and only one axis of two-fold symmetry or one and only one plane of symmetry or both it is a monoclinic crystal.

### Prominent Features.

Any face in the zone of the symmetry axis makes a  $90^\circ$  angle with the symmetry plane (or a face parallel to it). No other  $90^\circ$  angles occur.

The cross section of the zone of the symmetry axis is never rhombic or rectangular but markedly unsymmetrical.

The direction of the symmetry axis is not usually the long dimension, and the faces parallel to it are only alike in pairs.

No monoclinic crystal will consist of less than two kinds of faces and there will never be more than four corresponding faces on a crystal.

FIG. 26.

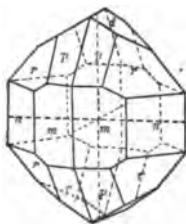


FIG. 27.

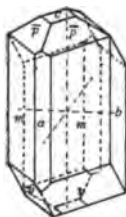
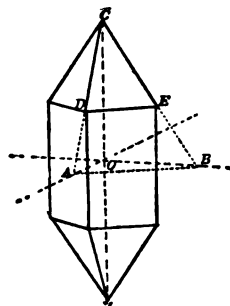


FIG. 28.



### Angles.

No zone has a constant series of angles for each species. The zone of the axis of symmetry can always be found and its angles measured and it is also usually easy to locate corresponding faces the angles between which are bisected by the symmetry plane. These two sets of angles have therefore been used in the table following.

Thus in Fig. 27  $c \wedge a = 105^\circ 50'$  is an angle in the zone of the symmetry axis and  $m \wedge m = 87^\circ 10'$ ,  $v \wedge v = 111^\circ 18'$  and  $\bar{p} \wedge \bar{p} = 131^\circ 31'$  are bisected by the plane of symmetry. These are recorded in the table as angles of pyroxene.

The important monoclinic minerals which often occur in macroscopic crystals may be classified as follows:

|  | Species.   | Angles in Zone of Symmetry Axis.    | Angles Bisected by Symmetry Plane.            | Other Important Angles. |
|--|------------|-------------------------------------|---|-------------------------|
| Easiest cleavage parallel to symmetry plane      | Colemanite | 110° 9',<br>111° 36'                | 107° 56',<br>140° 12',<br>126° 9'             | *90                     |
|  | Gypsum     | .....                               | 171° 30',<br>143° 48',<br>138° 40'            | *90                     |
|  | Realgar    | .....                               | 74° 26',<br>132° 3'                           |                         |
|  | Vivianite  | .....                               | 108° 02'                                      |                         |
|  | Wolframite | 118° 6',<br>124° 48',<br>117° 6'    | 100° 37',<br>98° 6',<br>117° 49'              |                         |
| Easiest cleavage perpendicular to symmetry plane | Azurite    | 135° 14',<br>137° 10',<br>132° 45'  | 99° 19',<br>119° 13',<br>90° 53',<br>*59° 13' | *90                     |
|  | Borax      | 106° 35'                            | *87° 0',<br>122° 33',<br>96° 32'              |                         |
|  | Epidote    | *115° 23',<br>128° 19',<br>155° 11' | 70° 4',<br>70° 29',<br>63° 5'                 |                         |
|  | Monazite   | 140° 48',<br>87° 17',<br>126° 29'   | 93° 26'                                       |                         |
|  | Orthoclase | 99° 42',<br>129° 44'                | 118° 47',<br>90° 7'                           |                         |
|  |            |                                     |   |                         |
| Cleavage angle bisected by plane of symmetry     | Amphibole  | 130° 6'                             | *124° 11',<br>148° 28'                        |                         |
|  | Pyroxene   | 105° 50',<br>148° 40'               | *87° 10',<br>120° 49',<br>131° 31'            |                         |
|  | Spodumene  | 110° 20'                            | *87° 0',<br>91° 26'                           |                         |
|  | Titanite   | 140° 43',<br>159°                   | *113° 31',<br>136° 11',<br>67° 57'            |                         |
| No cleavage                                      | Datolite   | 90° 9',<br>135°                     | 115° 13',<br>120° 56',<br>115° 21'            |                         |
|  |            |                                     |   |                         |

The micas and chlorites are usually pseudo-hexagonal.

### TRICLINIC SYSTEM.

#### Principal Characteristics.

If the crystal shows neither any axes nor any planes of symmetry it is a triclinic crystal.

\* = angle between easy cleavage planes.

**Prominent Features.**

There will be no right angles either between faces or edges. The only corresponding faces will be opposite (parallel) faces.

Triclinic crystals however may approximate in angles monoclinic crystals and only be distinguishable by inspection by the occurrence of faces which have no symmetrically placed associates.

**Angles.**

All corresponding faces being parallel, angles between adjacent faces are given. Two faces adjacent in one crystal may however be separated by truncating faces in another.

|                   | Interfacial and<br>Cleavage Angles | Angles between Common<br>Adjacent Faces |
|-------------------|------------------------------------|---|
| Albite.....       | 93° 36'                            | 127° 44', 120° 46'                      |
| Anorthite.....    | 94° 10'                            | 116° 3', 98° 46', 120° 31'              |
| Labradorite.....  | 93° 56'                            |   |
| Oligoclase.....   | 93° 28'                            | 128° 3', 98° 8', 120° 54'               |
| Amblygonite.....  | 104° 30'                           | 135° 30'                                |
| Chalcanthite..... | 123° 10'                           | 110° 10', 70° 22', 103° 27'             |
| Cyanite .....     | 101° 30'                           | 74° 16', 131° 42', 78° 58'              |
| Rhodonite.....    | 87° 32'                            | 107° 24'                                |

**CONSIDERATION OF CRYSTALS BY CRYSTALLOGRAPHIC AXES AND SYMBOLS.****Crystallographic Axes.**

The bounding planes or faces of crystals are defined in position by referring them to coordinate axes after the manner of analytical geometry. The coordinate axes are usually (though unfortunately) called crystallographic axes:

**Choosing Crystallographic Axes.**

It is always possible and indeed essential to choose as crystallographic axes those lines which are closely related to the symmetry of the crystal. If the choice be made in the following order the six systems result.

First, axes of symmetry.

Second, lines perpendicular to planes of symmetry.

Third, lines *in* a plane of symmetry parallel to edges, or faces.

Fourth, lines parallel or equally inclined to several faces of the crystal.

If there result more lines than are needed, preference should be given:

- (a) To directions at right angles to each other.
- (b) To interchangeable directions, that is, to directions such that the grouping of the faces about one is the same as the grouping of the faces about any other.

### The Six Crystal Systems.

The six systems may then be defined in terms of axes, each including all crystals which are, by the given rules, referred to a particular set of axes:

**THE TRICLINIC SYSTEM.**—Three non-interchangeable axes at oblique angles to each other.

**THE MONOCLINIC SYSTEM.**—Three non-interchangeable axes two of which are oblique to each other, the third is at right angles to the other two.

**THE ORTHORHOMBIC SYSTEM.**—Three axes at right angles but not interchangeable.

**THE TETRAGONAL SYSTEM.**—Three axes at right angles, of which two are interchangeable.

**THE HEXAGONAL SYSTEM.**—Four axes, three of which lie in one plane at sixty degrees to each other and are interchangeable, the fourth is at right angles to the other three.

**THE ISOMETRIC SYSTEM.**—Three interchangeable axes at right angles to each other.

### CRYSTAL FACES AND THEIR SYMBOLS.\*

#### Referring a Face to the Crystallographic Axes.

Whatever the position of any crystal face, *CDE*, Fig. 28, it must be either parallel to or capable of intersecting each of the chosen crystallographic axes.

Its position in space is absolutely determined if the numerical values of its intercepts *OA*, *OB* and *OC* on the crystallographic axes are known.

If stated as *relative* distances, for instance

$$OA : OB : OC = 0.7 : 1 : 1.46,$$

\* The symbols of Levy, Naumann, Dana, Goldschmidt are not used in this book. A description of these will be found in Goldschmidt's "Index der Krystallformen," Vol. 1.

these intercepts are independent of the *absolute* position of the face and represent any face parallel to it, that is any face in the same angular position.

### The Miller Indices and the Weiss Parametral Symbols.

Because of a simple relation between the intercepts of different faces (which will later be explained) the symbols which are most used are not the relative intercepts of the corresponding faces but simpler expressions from which these relative intercepts may be derived.

#### Parameters.

Both the Miller and the Weiss symbols require that the relative intercepts of some chosen face upon the crystallographic axes be known. These particular intercepts are hereafter spoken of as *Parameters*. In Fig. 29 of topaz the chosen face is *p* (parallel to a face of the enclosed dotted pyramid) and by calculation the parameters are  $a : b : c = 0.529 : 1 : 0.477$ .

#### The Miller Indices.

The Miller indices of any face *are those numbers which divided term by term into the parameters give as quotients the intercepts of the face*.

Conversely dividing the parameters by the intercepts will give the indices.

#### The Weiss Coefficients.

The Weiss parametral symbols state the parameter symbol  $a : b : c$  with coefficients and the Weiss *coefficients of any face are those numbers which multiplied term by term into the parameters give as products the intercepts of the face*.

The Miller indices and the Weiss coefficients are therefore reciprocally related.

#### Example.

In crystals of topaz there occurs a plane *f*, Fig. 29, for which the Miller indices are (021) and the Weiss symbol  $\infty a : b : 2c$ , but these symbols alone tell only that the face is parallel the first axis.

If, however, the parameters are known  $a : b : c = 0.529 : 1 : 0.477$ , then it follows from the two definitions that with respect to the other two axes the intercepts of the face *f* are  $OB : OC : 0.5 : 0.477$ , or as 1 : 0.954.

**CRYSTAL "FORMS" OR GROUPS OF EQUIVALENT FACES.**

Crystal faces which are directions of identical structure may be called "equivalent" faces. Such faces are sometimes closely alike in size and shape. Very frequently they have similar markings and luster and they always make the same angles with the crystallographic axes. Their symbols are therefore variants of one symbol.

The crystallographic form in any symmetry class is that assemblage of equivalent faces which satisfies the symmetry of

FIG. 29.

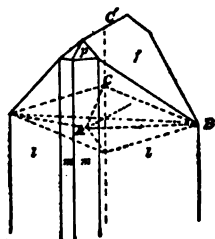
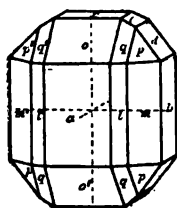


FIG. 30.



the class. A form may be one face or two faces or as many as forty-eight faces. It is not necessarily a closed form.

**Form Symbols.**

The symbol used is the symbol of any of the faces of the form. In the Miller indices, for instance,  $\{121\}$  signifies a form to which the face  $(121)$  belongs,  $\{ \quad \}$  conventionally being reserved for forms,  $( \quad )$  for faces.

**Combinations of Forms.**

A crystal may be bounded entirely by faces of one form. More frequently the bounding faces belong to two or more different forms. Such a crystal is said to be a combination of, or to be composed of, or to show such and such forms, the symbols being stated.

If one of the forms is notably more prominent than the others, for instance, the cube, the crystal is often described as a cube *modified* by the other forms.

**Zones.**

Zones are composed of faces all parallel to the same line. Their intersections are therefore parallel to this line and to each other.



It has sometimes been stated as a fourth law of crystals that the faces of crystals tend to occur in zones. In the clinographic and orthographic projections used in this book parallel edges of the crystal appear as parallel lines; therefore the prominent zones can easily be traced. For instance, in Fig. 30,  $m'$ ,  $l'$ ,  $a$ ,  $l$ ,  $m$ ,  $b$  are faces in one zone, as are  $p'$ ,  $q'$ ,  $o$ ,  $q$ ,  $p$ , or  $b$ ,  $d$ ,  $e$ ,  $c$  or  $o'$ ,  $a$ ,  $o$ ,  $c$ .

**THE OCCURRENCE OF CRYSTAL FACES IN SERIES AS EXPRESSED IN THE LAW OF SIMPLE MATHEMATICAL RATIO.**

A simple but very important relation is found to exist between all true crystal faces or crystals of any one substance which may be expressed as follows:

*If the relative intercepts of all the faces are reduced so that the same term in each is unity, then in all crystals of the same chemical substance, if the intercepts of any face are divided, term by term, by the corresponding intercepts of any other face, the quotients will be simple numbers or simple fractions or infinity.*

FIG. 31.

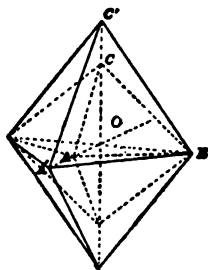
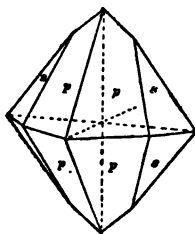


FIG. 32.



As corollaries to this it follows that the Miller Indices\* and the Weiss Coefficients, which are such quotients, must be simple numbers, or simple fractions or infinity.

Two pyramids like those shown in Fig. 31 conform to the law and could occur in the same crystal as in Fig. 32. These intercepts bear the following relation:

\* This law rests on many thousands of measurements. Its establishment is due to Haüy, for while de l'Isle's series of forms (derived by "replacing" the angles and other parts of some "primitive" form by planes) limited the angles of the planes only so as to retain the symmetry of the primitive form, Haüy found he could build the secondary planes by "regular decrections" each successive layer diminishing by the abstraction of one or more rows of particles (always some simple rational number) parallel to particular lines. Weiss expressed this mathematical relation by the use of crystal axes and parameter symbols.

$$\frac{OA'}{OA} = 2, \quad \frac{OB'}{OB} = 1, \quad \frac{OC'}{OC} = 3/2.$$

If  $OA$ ,  $OB$  and  $OC$  are taken as parameters the Miller and Weiss symbols become:

|                    | Miller. | Weiss             |
|--------------------|---------|-------------------|
| Inner pyramid..... | {111}   | $a : b : c$       |
| Outer pyramid..... | {364}   | $2a : b : 3/2, c$ |

The common bounding faces almost without exception have *very* simple indices, usually 0, 1, 2, 3 or 4. Somewhat larger numbers result for the smaller and less common faces. Occasionally crystal faces occur for which indices can not be called simple, such as (8, 14, 11) topaz, (11, 13, 1) cerussite, (3, 14, 20) fluorite, (28, 7, 24) barite.

Such indices may be the result of inaccurate measurements or of imperfect faces or, in those cases in which the faces are at angles *near* common faces (vicinal planes), may be due to disturbances or changed conditions during formation.

#### THE TYPE FACES IN ANY SYMMETRY CLASS.

In each symmetry class there are seven typically different positions in which a crystal face may occur with respect to the chosen crystallographic axes.

The *numerical* values of the Miller indices and of the Weiss coefficients are not needed in the type symbols. Letters, usually  $h$ ,  $k$  and  $l$  in the Miller indices and  $m$  and  $n$  in the Weiss coefficients, may be used.

In the different classes conventions differ somewhat and symbols with them. These differences are stated in subsequent chapters.

#### Determination of Type Symbols by Inspection.

After the axes have been chosen and placed in the conventional positions stated under each system, the determination of the type symbols may be conducted as follows in models and large crystals.

Place a straight edge or pencil in contact with a face and, keeping the contact, turn the straight edge until its relation to each axis has been noted.

First, note whether the face is parallel to any axis. If the straight edge *while in contact with the face* can be turned into a

position parallel to the axis, the face is parallel to the axis, the corresponding Miller index is 0 and the corresponding Weiss coefficient is  $\infty$ .

Second, note whether any two intercepts of the face are equal in this case, the corresponding indices (or the corresponding coefficients) are then expressed by the same letter.

If all intercepts are unlike all three letters will be used, the order depending upon the convention used in the symmetry class. If the face is the chosen unit face the indices and coefficients will all be unity whether the intercepts are equal or unequal.

#### THE CRYSTAL STRUCTURE.

Disregarding the relation between the chemical nature of substances and the crystal structure,\* the geometric forms of crystals and many of their physical characters prove a homogeneous structure, in which each particle is in a similar position with respect to those surrounding it; each is the center of a precisely similar group, and along any line, and all parallel lines, the particles are equally far apart.

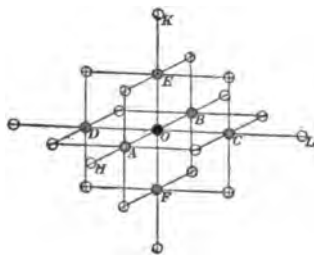


FIG. 33.

Such a structure is illustrated in Fig. 33, the particle  $O$  is surrounded by six similar particles  $A, B, C, D, E$  and  $F$  at fixed distances  $OA = OB, OC = OD$  and  $OE = OF$ . Each of the six is itself the center of a similar group, the intervals in the same direction being as before, that is  $AH = OA, CL = OC, EK = OE$  and so on.

Different substances differ in the grouping of their particles so that each has its own characteristic physical constants and characteristic geometric shapes. All this has been theoretically considered and the possible variation of regular grouping discussed.†

In all 230 types of structure are recognized, all belonging to the 32 classes of symmetry.

\* Article on "Crystallography," by W. J. Pope, Annual Rept. Progress Chemistry, 1908, Vol. 5, pp. 258-279.

† See Report of Committee "On Structure of Crystals," *Proc. Roy. Soc., Section C*, Glasgow, 1091, for a general review.

### The Possible "Forms" on Crystals of One Substance.

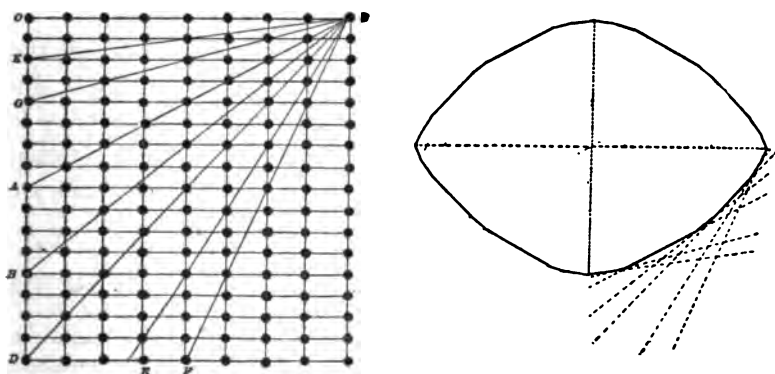
Experience proves that well-developed faces upon crystals of the same substance occur at particular angles dependent upon the structure and that if the structure is theorized for a given substance (with distances of particles apart corresponding to the parameters) it is found *that the net planes with most particles lie parallel to the bounding faces of the crystal*. To illustrate, let Fig. 34 represent a net plane through the crystallographic axes  $\bar{a}$  and  $\bar{b}$  of topaz ( $\bar{a} : \bar{b} = .5285 : 1$ ).

Draw lines connecting  $B$  with consecutive points in different directions.

The distances apart of consecutive points *increases* along different lines in the following order:

$BA, BD, BE, BF, BG, BH, BK, BL, BM$ .

FIG. 34.



The probable prisms of topaz.

Calculating the angle of each line with  $OD$  and comparing with the angles of occurring prisms of topaz—

|                               |         |         |         |         |         |         |         |
|-------------------------------|---------|---------|---------|---------|---------|---------|---------|
| Direction.....                | BA      | BD      | BE      | BF      | BG      | BH      | BK      |
| Calculated angle.....         | 62° 08' | 43° 25' | 32° 14' | 25° 19' | 75° 12' | 51° 35' | 82° 28' |
| Face of topaz corresponding . | (110)   | (120)   | (130)   | (140)   | (210)   | (230)   | (410)   |

That is, all of the nine directions represent actual topaz prisms and moreover the most common of all are (110) ( $BA$ ), and (120)  $BD$ , the directions of most frequent particles. The cross-section of such a group of prisms is shown.

If the net plane through the axes  $a$  and  $c$  be similarly constructed for topaz, with distances of particles apart corresponding to the parameters  $a : c = 0.529 : 0.477$  (or  $1 : 0.901$ ), it would be found similarly that the directions which passed through most points would correspond to such forms as  $\{021\}$  and  $\{041\}$ .

Rogers in a similar figure shows that if the net plane through two isometric axes is considered the directions with most frequent points correspond to forms in the following order.

Cube  $\{100\}$ , dodecahedron  $\{110\}$ , tetrahedrons (or pyritohedrons)  $\{210\}$   $\{310\}$   $\{320\}$ .

These constructions for simplicity have considered only the relations to two axes and assumed parallelism to the third, but the positions of faces which intersect all axes are just as strictly indicated by a consideration of the entire "space lattice."

#### Form Names.

Two methods of naming forms exist both of which are based to a considerable extent on the shape of the form but in the one some attention is paid to the position of their faces on the crystal and in the other, except in the case of domes and sphenoids, this is disregarded. The latter plan leads to greater uniformity in names,† the former is in more general use and has been retained in this book. It is of relatively little importance what names are used, the forms are better expressed by their symbols.

\* Introduction to Study of Minerals, p. 73.

† The type names by this method are "pedion" a single face, "pinacoid" two parallel faces, "dome" two planes intersecting in a plane of symmetry, "sphenoid" two planes intersecting on a two fold axis, "prism" three or more planes with parallel intersections, "pyramids" three or more planes intersecting at a common point, "bipyramids" two pyramids "base to base." To these must be added scalenohedrons, trapezohedrons, rhombohedrons, and the usual names of the isometric system.

## CHAPTER II.

### TRICLINIC SYSTEM.\*

THE Triclinic System includes two classes in both of which the crystallographic axes are three lines oblique to each other and not interchangeable.

#### PINACOIDAL CLASS. 2.

No. 31. Holohedry, *Liebsch*. No. 31. Normal Class, *Dana*.

#### Choosing Crystallographic Axes.

Usually the intersections of three prominent faces are chosen as axes and one is conventionally made the vertical axis  $c$ , the others the macro or  $\bar{b}$  axis and the brachy or  $a$  axis.

#### The Seven Type Forms.

Each form consists of two parallel faces as follows :

1. TETRAPYRAMID. —  $na : \bar{b} : mc$ ;  $\{hkl\}$ .

Two parallel faces which intersect all axes, Fig. 35. For any set of intercepts four independent forms result which if combined make a complete triclinic pyramid as shown in Fig. 36. Fig. 43

FIG. 35.

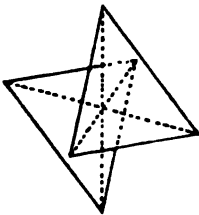


FIG. 36.

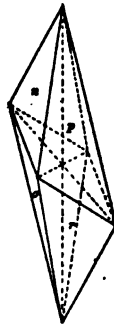
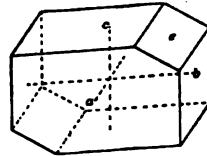


FIG. 37.



shows two tetra-pyramids  $p' = a : b : c = 111$  and  $'p = a : b' : c = 1\bar{1}\bar{1}$  of the mineral axinite.

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\* Also known as Tetarto prismatic, Ein-und-eingliedrige, Triclinohedral, Clinorhomboidal, Anorthic, Doubly oblique and Asymmetric.

2. HEMI BRACHY DOME. —  $\infty a : \bar{b} : mc$ ;  $\{okl\}$ .

Two faces each parallel to the brachy axis. The face  $e$  and its opposite, Fig. 37, modifying the three pinacoids.

3. HEMI MACRO DOME. —  $a : \infty \bar{b} : mc$ ;  $\{hol\}$ .

Two faces each parallel to the macro axis. The face  $d$  and its opposite, Fig. 38, modifying the pinacoids.

4. HEMI PRISM. —  $na : \bar{b} : \infty c$ ;  $\{hko\}$ .

Two faces each parallel to the vertical axis. The face  $m$  and its opposite, Fig. 39, modifying the pinacoids.

5. BASAL PINACOID. —  $\infty a : \infty \bar{b} : c$ ;  $\{001\}$ .

Two faces each parallel to both the macro and brachy axes. The faces  $c$  in Figs. 38 to 40.

FIG. 38.

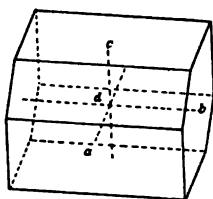


FIG. 39.

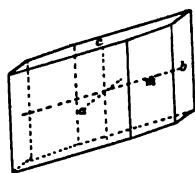
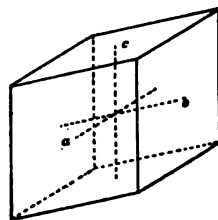


FIG. 40.



6. BRACHY PINACOID. —  $\infty a : \bar{b} : \infty c$ ;  $\{010\}$ .

Two faces, each parallel to the brachy and vertical axes. The faces  $b$  of Figs. 38 to 40.

7. MACRO PINACOID. —  $a : \infty \bar{b} : \infty c$ ;  $\{100\}$ .

Two faces each parallel to the macro and vertical axes. The faces  $a$  of Figs. 38 to 40.

#### Combinations in the Triclinic System.

Fig. 41 shows a crystal of chalcantite with brachy pinacoid  $b$ ,

FIG. 41.

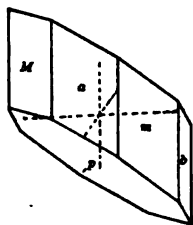


FIG. 42.

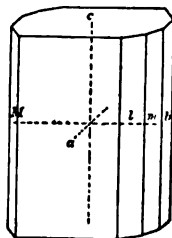
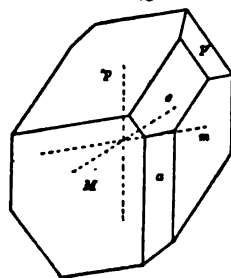


FIG. 43.



macro pinacoid  $a$ , right hemi prism  $m$ , left hemi prism  $M$  and lower left tetra pyramid  $p$ . Fig. 42 shows a crystal of cyanite with the three pinacoids  $a$ ,  $b$  and  $c$ , the right  $m$ , and left  $M$  hemi unit prisms and a right hemi brachy prism  $l = (2a : \bar{b} : \infty c) ; \{120\}$ .

Fig. 43 shows a crystal of axinite with both hemi prisms  $m$  and  $M$ , macro pinacoid  $a$ , upper right and upper left unit pyramids  $p'$  and  $p$  and a macro dome  $e = (a : \infty \bar{b} : 2c) ; \{201\}$ .

#### Tabulation of the Seven Type Forms.

| NAME.                            | FACES. | WEISS.                                 | MILLER.   |
|----------------------------------|--------|--|-----------|
| Each face intersects all axes :  |        |  |           |
| 1. TETRA PYRAMID,                | 2      | $na : \bar{b} : mc'$                   | $\{hkl\}$ |
| Each face parallel to one axis : |        |  |           |
| 2. HEMI BRACHY DOME,             | 2      | $\infty a : \bar{b} : mc'$             | $\{okl\}$ |
| 3. HEMI MACRO DOME,              | 2      | $\bar{a} : \infty \bar{b} : mc'$       | $\{hol\}$ |
| 4. HEMI PRISM,                   | 2      | $na : \bar{b} : \infty c'$             | $\{hko\}$ |
| Each face parallel to two axes : |        |  |           |
| 5. BASAL PINACOID,               | 2      | $\infty a : \infty \bar{b} : c$        | $\{oor\}$ |
| 6. BRACHY PINACOID,              | 2      | $\infty a : \bar{b} : \infty c'$       | $\{oro\}$ |
| 7. MACRO PINACOID,               | 2      | $\bar{a} : \infty \bar{b} : \infty c'$ | $\{1oo\}$ |

#### Other Classes in Triclinic System.

One other class known as the unsymmetrical class exists and in this each form is a single face. No examples among minerals are known but among salts there is calcium thiosulfate,  $\text{CaS}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$ .



## CHAPTER III.

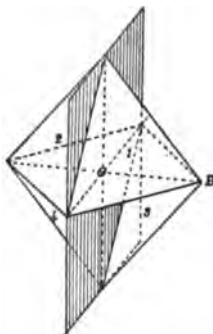
### MONOCLINIC SYSTEM.\*

THE monoclinic system includes three classes of symmetry, in all of which the crystallographic axes may be chosen so that two are oblique to each other and the third normal to the other two. The axes are not interchangeable.

#### PRISMATIC CLASS. 5.

No. 28. Holohedry, *Liebisch*. No. 28. Normal Group, *Dana*.

FIG. 44.



All the common monoclinic minerals occur in crystals symmetrical to one plane and to one axis at  $90^\circ$  to the plane, Fig. 44.

#### Choosing Crystallographic Axes.

The axis of symmetry is always chosen as the axis  $\bar{b}$  and placed horizontally from right to left.

Two other axes, oblique to each other, are chosen † *in the plane* of symmetry one of which is placed vertically and denoted by  $\bar{c}$  the other  $\bar{a}$  "the clino" dips downward from back to front. The acute angle between the verti-

cal and clino axis is called  $\beta$ .

#### Tabulation of the Seven Type Forms.

| NAME.                            | FACES. | WEISS.                                      | MILLER.   |
|----------------------------------|--------|---|-----------|
| Each face intersects all axes :  |        |   |           |
| 1. HEMI PYRAMID,                 | 4      | $n\bar{a} : \bar{b} : m\bar{c}$             | $\{hkl\}$ |
| Each face parallel to one axis : |        |   |           |
| 2. CLINO DOME,                   | 4      | $\infty a : \bar{b} : m\bar{c}$             | $\{0kl\}$ |
| 3. HEMI ORTHO DOME,              | 2      | $\bar{a} : \infty \bar{b} : m\bar{c}$       | $\{h0l\}$ |
| 4. PRISM,                        | 4      | $n\bar{a} : \bar{b} : \infty \bar{c}$       | $\{hko\}$ |
| Each face parallel to two axes : |        |   |           |
| 5. BASAL PINACOID,               | 2      | $\infty a : \infty \bar{b} : \bar{c}$       | $\{001\}$ |
| 6. CLINO PINACOID,               | 2      | $\infty a : \bar{b} : \infty \bar{c}$       | $\{010\}$ |
| 7. ORTHO PINACOID,               | 2      | $\bar{a} : \infty \bar{b} : \infty \bar{c}$ | $\{100\}$ |

\* Also called Hemiprismatic, Zwei-und-eingliedridge, Monoclinohedral, Clinorhombic, Monosymmetric.

† For instance the intersections of the pinacoids would determine both directions, or the edges of any prism and any clino dome would determine both directions.

**Description of the Type Forms.****1. HEMI PYRAMID.** —  $na : b : mc ; \{hkl\}$ .

Four faces each intersecting all the axes in distances not simple multiples of each other. Fig. 45 shows a negative form cut off by a positive ortho dome  $o$ .

For any set of intercepts two independent forms result which combined form a complete pyramid. For instance the combination of  $\bar{p}$ , Fig. 45, with the corresponding positive form  $p$  gives Fig. 46.

FIG. 45.

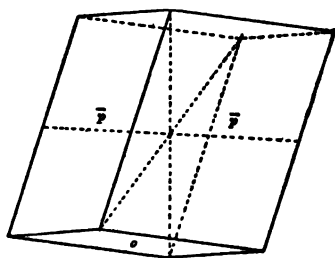
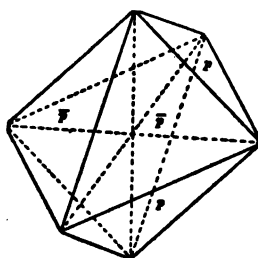


FIG. 46.

**2. CLINO DOME.** —  $\infty a : b : mc ; \{okl\}$ .

Four faces, each parallel to the clino axis and cutting the vertical and ortho axes in distances *not* simply proportionate. The faces  $d$  of Fig. 47 combined with two pinacoids.

**3. HEMI ORTHO DOME.** —  $a : \infty b : c ; \{hol\}$ .

Two opposite faces, each parallel to the ortho axis and cutting the clino and vertical axes in distances not simply proportionate. The faces  $o$  in Figs. 45 and 48 are the positive hemi ortho dome. Another independent form exists with the same intercepts.

FIG. 47.

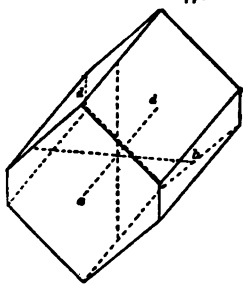


FIG. 48.

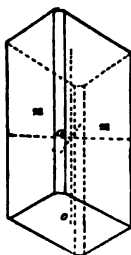
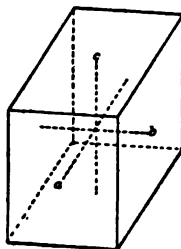


FIG. 49.

**4. PRISM.** —  $na : b : \infty c ; \{hko\}$ .

Four faces, each parallel to the vertical axis, and cutting the

basal axes in distances not simply proportionate. The faces  $m$  in Fig. 48 and subsequent figures.

5. BASAL PINACOID. —  $\infty a : \infty b : c$ ;  $\{001\}$ .

Two faces, each parallel to both basal axes. The faces  $c$  of Fig. 49 and subsequent figures.

6. CLINO PINACOID. —  $\infty a : b : \infty c$ ;  $\{010\}$ .

Two faces, each parallel to the clino and vertical axes. The faces  $b$  of Fig. 49 and subsequent figures.

7. ORTHO PINACOID. —  $a : \infty b : \infty c$ ;  $\{100\}$ .

Two faces, each parallel to the ortho and vertical axes. The faces  $a$  of Fig. 49 and subsequent figures.

#### Combinations in the Prismatic Class.

*Pyroxene*. — Axes  $a : b : c = 1.092 : 1 : 0.589$ ;  $\beta = 74^\circ 10' 9''$ .

Fig. 50 shows the three pinacoids,  $a$ ,  $b$  and  $c$ , the unit prism  $m$ , the negative unit hemi-pyramid  $\bar{p}$  and the positive hemi-pyramid  $v = (a : b : 2c)$ ;  $\{22\bar{1}\}$ . Fig. 52 is the same without  $v$  and Fig. 51 omits also the basal pinacoid  $c$ . Fig. 53 shows the unit prism  $m$ , the

FIG. 50.

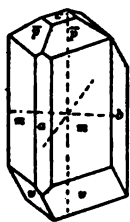


FIG. 51.

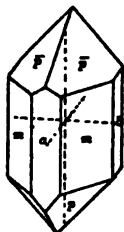


FIG. 52.



FIG. 53.



basal pinacoid  $c$ , two positive hemi-pyramids  $v$  and  $w = (a : b : 3c)$ ;  $\{33\bar{1}\}$ ; and a clino dome  $z = (\infty a : b : 2c)$ ;  $\{021\}$ .

*AMPHIBOLE*. — Axes  $a : b : c = 0.551 : 1 : 0.293$ ;  $\beta = 73^\circ 58' 4''$ .

FIG. 54.

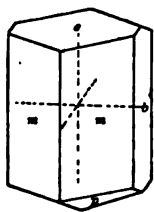


FIG. 55.

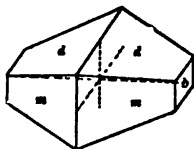


FIG. 56.



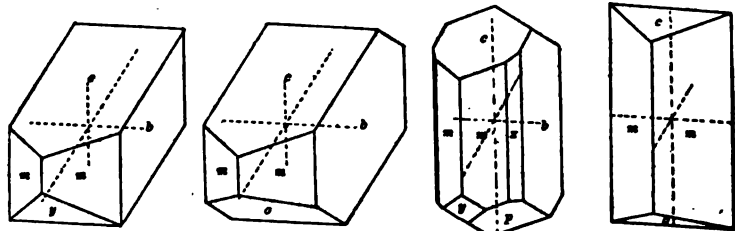
Fig. 54 shows the unit prism  $m$ , the basal and clino pinacoids,  $c$  and  $b$  and the positive unit hemi pyramid  $p$ . Fig. 55 shows the unit prism, clino pinacoid and unit clino dome  $d = (\infty a : b : c)$ .  $\{011\}$ . Fig. 56 shows the same except that the clino pinacoid  $b$  is replaced by the ortho pinacoid  $a$ .

FIG. 57.

FIG. 58.

FIG. 59.

FIG. 60.



ORTHOCLASE. — Axes  $a : b : c = 0.658 : 1 : 0.555$ ;  $\beta = 63^\circ 56' 46''$ .

Fig. 57 shows the unit prism  $m$ , clino and basal pinacoids  $b$  and  $c$ , and positive hemi orthodome  $y = (a : \infty b : 2c)$ ;  $\{20\bar{1}\}$ . In Fig. 58  $y$  is replaced by  $o = (a : \infty b : c)$ ;  $\{10\bar{1}\}$  and in Fig. 60 the clino pinacoid is omitted. Fig. 59 includes the forms of 57 and also a clino prism  $z = (3a : b : \infty c)$ ;  $\{130\}$  and the unit pyramid  $p$ .

#### Other Classes in the Monoclinic System.

Two other classes are known:

3. CLASS OF THE MONOCLINIC SPHENOID. With one axis of 2-fold symmetry.

Example: Fichtelite,  $C_{18}H_{32}$ . Examples in salts are tartaric acid and cane-sugar,  $C_{12}H_{22}O_{11}$ .

4. CLASS OF THE MONOCLINIC DOME. With one plane of symmetry.

Examples: The rare minerals clinohedrite and scolecite.

## CHAPTER IV.

### ORTHORHOMBIC SYSTEM.

THE orthorhombic\* system includes three classes of symmetry, in all of which the crystallographic axes may be chosen at right angles to each other, but are not interchangeable.

In this system of moderate symmetry certain facts common to all crystals can be better illustrated and understood than in the other systems. Two of these are discussed under the headings "Series" and "Symbols for Individual Faces."

#### Series.

All forms which ever appear upon crystals of the same substance belong to one series. That is, their faces occur at such angles that if one of the faces is taken as the unit and its intercepts expressed by  $a : b : c$  all other faces may be simply expressed in terms of this face. For instance in the crystals of topaz, Figs. 78 to 80, the calculated intercepts for certain faces and their symbols, when  $p$  is taken as the unit face, are as follows :

| FACE. | CALCULATED INTERCEPTS.   | SYMBOLS IN TERMS OF $p$ .                            |
|-------|--------------------------|--|
| $p$   | 0.528 : 1 : 0.477        | $\bar{a} : \bar{b} : \bar{c}$ {111}                  |
| $i$   | 0.528 : 1 : 0.318        | $\bar{a} : \bar{b} : \frac{2}{3}\bar{c}$ {223}       |
| $q$   | 0.528 : 1 : 0.954        | $\bar{a} : \bar{b} : 2\bar{c}$ {221}                 |
| $m$   | 0.528 : 1 : $\infty$     | $\bar{a} : \bar{b} : \infty\bar{c}$ {110}            |
| $l$   | 1.056 : 1 : $\infty$     | $2\bar{a} : \bar{b} : \infty\bar{c}$ {120}           |
| $f$   | $\infty : 1 : 0.954$     | $\infty\bar{a} : \bar{b} : 2\bar{c}$ {021}           |
| $h$   | 0.528 : $\infty : 0.318$ | $\bar{a} : \infty\bar{b} : \frac{2}{3}\bar{c}$ {203} |

#### Symbols for Individual Faces.

For correct projection and for use in calculation face symbols are needed which show the particular angle in which the face occurs. These are simply obtained by considering positive and negative directions upon the crystal as in the figure. Then the different faces of Fig. 61, for which the form symbol is  $na : \bar{b} : mc$  or  $\{hkl\}$ , have their individual symbols,  $(hkl)$ ,  $(h\bar{k}l)$ ,  $(h\bar{k}\bar{l})$ ,  $(hk\bar{l})$ , the minus signs indicating the negative direction and the paren-

\* Also called Prismatic, Rhombic, Ein-und-einaxige, Anisometric and Trimetric.

theses ( ) typifying a face as opposed to { } for a form. Or in Weiss's Symbols the equivalents may be obtained either by use of minus signs or a (') prime upon the negative intercept thus the equivalent for  $(h\bar{k}l)$  would  $na:\bar{b}':mc'$ .

### PYRAMIDAL CLASS. 8.

No. 25. Holohedry, *Liebsch.* No. 25. Normal Group, *Dana.*

Almost all orthorhombic minerals crystallize in forms symmetrical to three planes at right angles to each other, as in Fig. 62, the intersections of these being axes of two-fold symmetry.

FIG. 61.

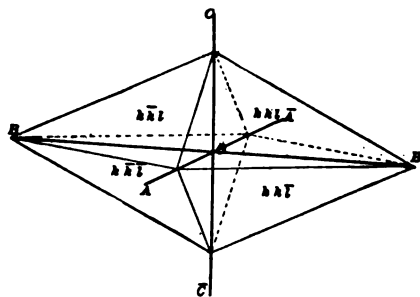
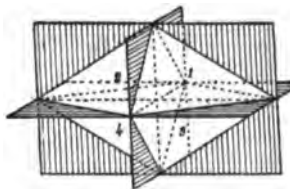


FIG. 62.



### Choosing Crystallographic Axes.

The axes of symmetry are the crystallographic axes. One,  $c$ , is placed vertically. Of the two others the one on which the intercept of the chosen unit face is the longer, is placed from left to right, and called the *macro* or  $\bar{b}$  axis; the other axis, placed from front to back, is called the *brachy* or  $a$  axis.

The unit face chosen will if possible be a face of frequent occurrence which intersects all the axes, or on account of similarity of crystals to some species of related composition, another choice may be made or the values  $\bar{a}$ ,  $\bar{b}$  and  $c$  may result from two different faces or from cleavages.

### Tabulation of the Seven Type Forms.

| NAME.                            | FACES. | WEISS.                      | MILLER.   |
|----------------------------------|--------|-----------------------------|-----------|
| Each face intersects all axes :  |        |                             |           |
| 1. RHOMBIC PYRAMID.              | 8      | $na:\bar{b}:mc$             | $\{hkl\}$ |
| Each face parallel to one axis : |        |                             |           |
| 2. BRACHY DOME.                  | 4      | $\infty \bar{a}:\bar{b}:mc$ | $\{0kl\}$ |
| 3. MACRO DOME.                   | 4      | $\bar{a}:\infty \bar{b}:mc$ | $\{h0l\}$ |
| 4. RHOMBIC PRISM.                | 4      | $na:\bar{b}:\infty c$       | $\{hko\}$ |

| NAME.                            | FACES. | WEISS.                          | MILLER.   |
|----------------------------------|--------|---------------------------------|-----------|
| Each face parallel to two axes : |        |                                 |           |
| 5. BASAL PINACOID.               | 2      | $\infty a : \infty \bar{b} : c$ | $\{001\}$ |
| 6. BRACHY PINACOID.              | 2      | $\infty a : b : \infty c$       | $\{010\}$ |
| 7. MACRO PINACOID.               | 2      | $a : \infty b : \infty c$       | $\{100\}$ |

### Description of the Type Forms.

1. RHOMBIC PYRAMID.— $na : \bar{b} : mc ; \{hkl\}$ .

Eight faces, each of which cuts the three axes in the same relative distances, which are never simple multiples of each other. In the ideal forms the faces are equal scalene triangles.

A pyramid may be composed either of faces with the unit intercepts, or the faces may be at other angles, with any one or two of the intercepts simple multiples of the unit intercepts.

For instance if in the series of figures 63 to 67 the faces  $p$  constitute the unit pyramid  $a : \bar{b} : c ; \{111\}$ ; then a series of pyramids which might occur with this would have different symbols and names. The pyramid  $s$ , shown in Fig. 63 enclosing  $p$  and in Fig.

FIG. 63.

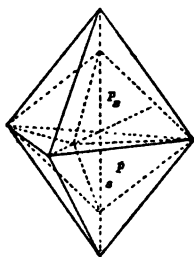


FIG. 64.

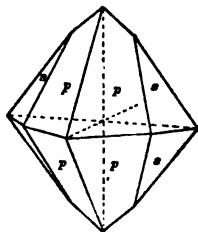


FIG. 65.

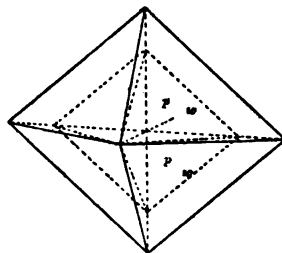


FIG. 66.

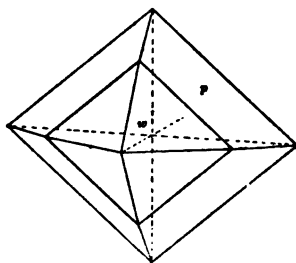
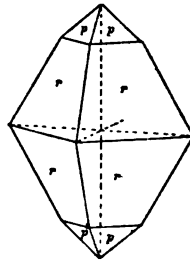


FIG. 67.



64 combined with  $p$ ; would be called a *brachy* pyramid, its symbol being  $2a : \bar{b} : \frac{3}{2}c ; \{364\}$ .

The pyramid  $w$  shown in Fig. 65 enclosing  $p$  and in Fig. 66 combined with  $p$  would be called a *macro* pyramid, its symbol being  $a : \frac{2}{3}\bar{b} : \frac{2}{3}c$ ;  $\{322\}$ ; and the pyramid  $r$  shown in Fig. 67 combined with  $p$  would be called a *unit series* pyramid, its symbol being  $a : \bar{b} : 2c$ ;  $\{221\}$ .

2. BRACHY DOME. —  $\infty a : \bar{b} : mc$ ;  $\{okl\}$ .

Four faces, each parallel to the brachy axis but cutting the macro axis and vertical axis in distances *not* simply proportionate. The faces  $d$  in Fig. 68.

3. MACRO DOME. —  $a : \infty \bar{b} : mc$ ;  $\{hol\}$ .

Four faces, each parallel to the macro axis but cutting the brachy axis and the vertical axis in distances *not* simply proportionate. The faces  $o$  in Fig. 69.

FIG. 68.

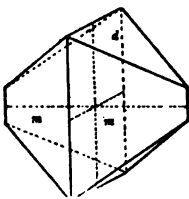
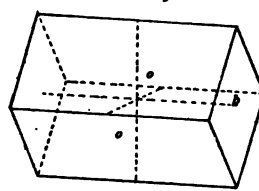


FIG. 69.



4. RHOMBIC PRISM. —  $na : \bar{b} : \infty c$ ;  $\{hko\}$ .

Four faces, each parallel to the vertical axis and cutting the basal axes in distances *not* simply proportionate.

The intercepts on the basal axes may be in the unit ratio or

FIG. 70.

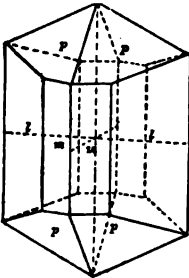
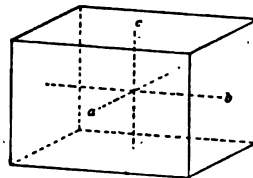


FIG. 71.



one of the intercepts may be *relatively* lengthened just as in the pyramids.

The faces  $m$  in Fig. 68. In Fig. 70 if  $p$  is the unit pyramid then, relatively,  $m$  is the unit prism  $a : \bar{b} : \infty c$ ;  $\{110\}$ ; and  $l$  is a brachy prism  $2a : b : \infty c$ ;  $\{120\}$ .



5. BASAL PINACOID. —  $\infty a : \infty \bar{b} : c$ ;  $\{001\}$ .

Two faces, each parallel to the basal axes. The faces  $c$  in Figs. 71–80.

6. BRACHY PINACOID. —  $\infty a : \bar{b} : \infty c$ ;  $\{010\}$ .

Two faces, each parallel to the brachy and vertical axes. The faces  $b$  in Figs. 69 and 71.

7. MACRO PINACOID. —  $a : \infty \bar{b} : \infty c$ ;  $\{100\}$ .

Two faces, each parallel to the macro and vertical axes. The faces  $a$  in Fig. 71.

#### Combinations in the Pyramidal Class.

*Barite*. — Axes  $a : \bar{b} : c = 0.815 : 1 : 1.313$ .

The prevailing faces are the unit prism  $m$ , the basal pinacoid  $c$ , the macro dome  $n = (a : \infty \bar{b} : \frac{1}{2}c)$ ;  $\{102\}$ ; and the brachy dome  $d = (\infty a : \bar{b} : c)$ ;  $\{011\}$ .

FIG. 72.



FIG. 73.

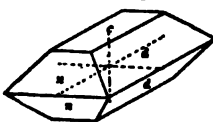


FIG. 74.



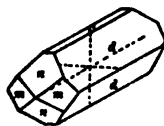
FIG. 75.



FIG. 76.



FIG. 77.



All of these are shown in Fig. 77. Fig. 76 contains also the brachy pinacoid  $b$  and Fig. 74 the macro pinacoid  $a$ . Figs. 72, 73 and 75 are simpler combinations of the same forms.

*Topaz*. — Axes  $a : \bar{b} : c = 0.528 : 1 : 0.477$ .

FIG. 78.

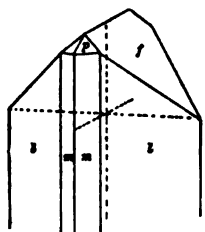


FIG. 79.

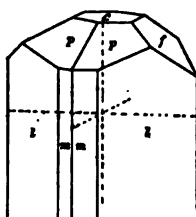


FIG. 80.

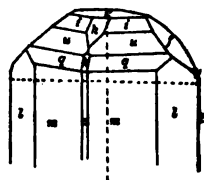


Fig. 78 shows the unit pyramid  $p$ , unit prism  $m$ , brachy prism  $l = (2a : \bar{b} : \infty c)$ ;  $\{120\}$ ; and the brachy dome  $f = (\infty a : \bar{b} : 2c)$ ;

$\{021\}$ . Fig. 79 shows the same forms with the basal pinacoid  $c$  and Fig. 80 shows all of 79 and also two other pyramids  $i = (a : \bar{b} : \frac{2}{3}c)$ ;  $\{223\}$ ;  $q = (a : \bar{b} : 2c)$ ;  $\{221\}$ ; and two macro-domes  $h = (a : \infty \bar{b} : \frac{2}{3}c)$ ;  $\{203\}$ ; and  $k = (a : \infty \bar{b} : 2c)$ ;  $\{201\}$ .

---

#### OTHER CLASSES OF THE ORTHORHOMBIC SYSTEM.

6. CLASS OF THE RHOMBIC SPHENOID.—With three axes of two-fold symmetry at  $90^\circ$  to each other. Examples—Epsomite and goslarite.

7. HEMIMORPHIC CLASS.—With two planes of symmetry at  $90^\circ$  to each other, intersecting in an axis of two-fold symmetry. Examples—Calamine, stephanite and prehnite.

## CHAPTER V.

### TETRAGONAL SYSTEM.\*

IN all tetragonal forms the crystallographic axes can be chosen at right angles to each other and so that two will be interchangeable, that is will be surrounded by exactly the same number of faces and with corresponding faces at the same angles. The grouping of faces about the third axis will not be the same as to angles and not necessarily the same as to number of faces.

#### Series.

A substance can only occur in forms of one class and in forms of *one series* in that class.

Because of the two interchangeable axes the intercepts of any face upon these will be simple multiples of each other. The intercept upon the vertical axis will bear no simple relation to these but *when two different faces are compared* there will be found a simple relation between the corresponding intercepts of all three axes.

Thus for zircon the common forms are *p*, *m*, *u* and *x* of Figs. 89 to 92. For these the intercepts and the symbols, if *p* be taken as the unit, are :

|          |   |       |
|----------|---|-------|
| <i>p</i> | 1 : 1 : 0.64 = <i>a</i> : <i>a</i> : <i>c</i> ;     | {111} |
| <i>m</i> | 1 : 1 : ∞ = <i>a</i> : <i>a</i> : ∞ <i>c</i> ;      | {110} |
| <i>u</i> | 1 : 1 : 1.92 = <i>a</i> : <i>a</i> : 3 <i>c</i> ;   | {331} |
| <i>x</i> | 1 : 3 : 1.92 = <i>a</i> : 3 <i>a</i> : 3 <i>c</i> ; | {311} |

### CLASS OF THE DITETRAGONAL PYRAMID. 15.

No. 18. Holohedry, *Liebis*ch. No. 6. Normal, *Dana*.

#### Symmetry of the Class.

Forms in this class are symmetrical to one conventionally horizontal plane and to four vertical planes at forty-five degrees to each other, Fig. 81. The intersections of these planes with each other are axes of symmetry and of these *CC* is an axis of fourfold symmetry.

---

\* Also called Pyramidal, Viergliedrige, Zwei-und-einaxige, Monodimetric, Quadratic and Dimetric.

**Choosing Crystallographic Axes.**

The axis of fourfold symmetry is chosen as the vertical axis  $c$  and either pair of alternate horizontal axes as the interchangeable axes  $a$ . Let  $h$  be the index on the axis with the shortest intercept.

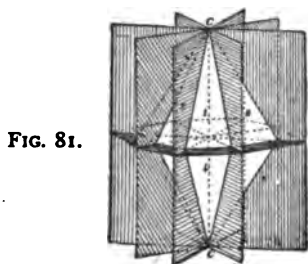


FIG. 81.

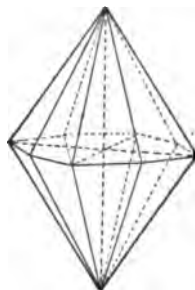


FIG. 82.

**Tabulation of the Seven Type Forms.**

| NAME.                       | FACES. | WEISS.                    | MILLER.   |
|-----------------------------|--------|---------------------------|-----------|
| Each face oblique to $c$ .  |        |                           |           |
| 1. DITETRAGONAL PYRAMID.    | 16     | $a : na : mc$             | $\{hkl\}$ |
| 2. PYRAMID OF SECOND ORDER. | 8      | $a : \infty a : mc$       | $\{hol\}$ |
| 3. PYRAMID OF FIRST ORDER.  | 8      | $a : a : mc$              | $\{hhl\}$ |
| Each face horizontal.       |        |                           |           |
| 4. BASAL PINACOID.          | 2      | $\infty a : \infty a : c$ | $\{001\}$ |
| Each face vertical.         |        |                           |           |
| 5. DITETRAGONAL PRISM.      | 8      | $a : na : \infty c$       | $\{hko\}$ |
| 6. PRISM OF SECOND ORDER.   | 4      | $a : \infty a : \infty c$ | $\{100\}$ |
| 7. PRISM OF FIRST ORDER.    | 4      | $a : a : \infty c$        | $\{110\}$ |

**Description of the Type Forms.**

1. DITETRAGONAL PYRAMID. —  $a : na : mc$ ;  $\{hkl\}$ .

Sixteen faces, Fig. 82, each cutting the two basal axes at unequal but simply proportionate distances, and the vertical axis at a distance *not* simply proportionate to the other distances. In the ideal forms the faces are scalene triangles.

2. PYRAMID OF SECOND ORDER. —  $a : \infty a : mc$ ;  $\{hol\}$ .

Eight faces, Fig. 84, each parallel to one horizontal axis, and cutting the other and the vertical axis at distances not simple multiples of each other. In ideal forms the faces are isosceles triangles.

3. PYRAMID OF FIRST ORDER. —  $a : a : mc$ ;  $\{hhl\}$ .

Eight faces, Fig. 83, each cutting the horizontal axes at equal distances, and the vertical axis at a distance *not a simple multiple*

of the basal intercepts. In ideal forms the faces are isosceles triangles.

Although there is an arbitrary choice of axes which determines the order of the pyramid, yet a first order unit  $a : a : c \{111\}$  has not the same angles as a second order unit  $a : \infty a : c \{101\}$ . For instance Figs. 83 and 84 represent these for the mineral *scheelite* and Fig. 85 shows the same forms combined, but the supplement angle  $pp' = 79^\circ 55\frac{1}{2}'$  whereas  $dd' = 72^\circ 40\frac{1}{2}'$ .

FIG. 83.

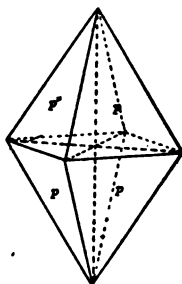


FIG. 84.

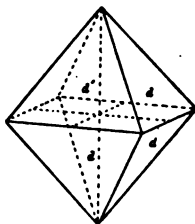
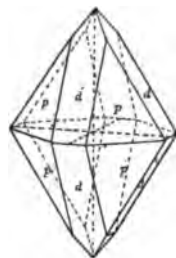


FIG. 85.



#### 4. BASAL PINACOID. — $\infty a : \infty a : c ; \{001\}$ .

Two faces, each parallel to both the horizontal axes. The faces  $c$  of Figs. 86 to 88.

FIG. 86.

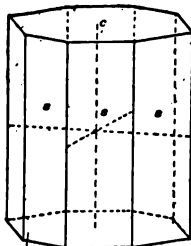


FIG. 87.

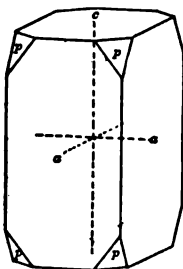
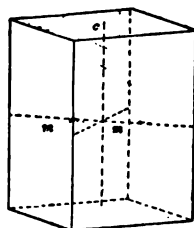


FIG. 88.



#### 5. DITETRAGONAL PRISM. — $a : na : \infty c ; \{hko\}$ .

Eight faces, each parallel to the vertical axis and cutting the two basal axes in distances unequal but simply proportionate. The faces  $s$ , Fig. 86.

The adjacent interfacial angles can not be equal, for then the symbol would be  $a : 2.4142 a : \infty c$  which is opposed to the law of rational intercepts ( $\text{Cotangent } 22^\circ 30' = 2.414213$ ).

#### 6. PRISM OF SECOND ORDER. — $a : \infty a : \infty c ; \{100\}$ .

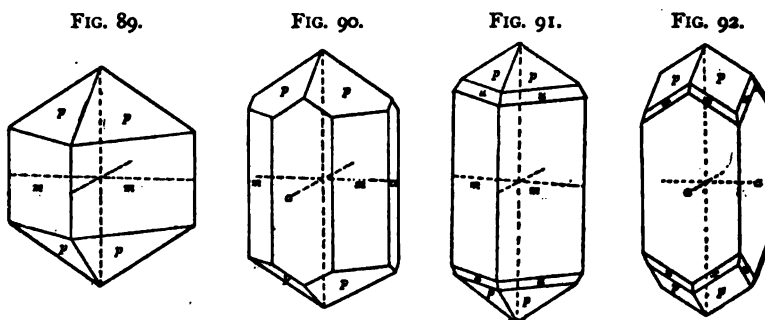
Four faces each parallel to the vertical axis and to one basal axis. The interfacial angles are  $90^\circ$ . The faces  $a$ , Figs. 87, 90, 94, etc.

7. PRISM OF FIRST ORDER. —  $a : a : \infty c$ ;  $\{110\}$ .

Four faces, each parallel to the vertical axis and cutting the basal axes at equal distances from the center. The interfacial angles are  $90^\circ$ . The faces  $m$ , Figs. 88, 89, 90, etc.

**Series and Combinations in the Class of Ditetragonal Pyramid.**

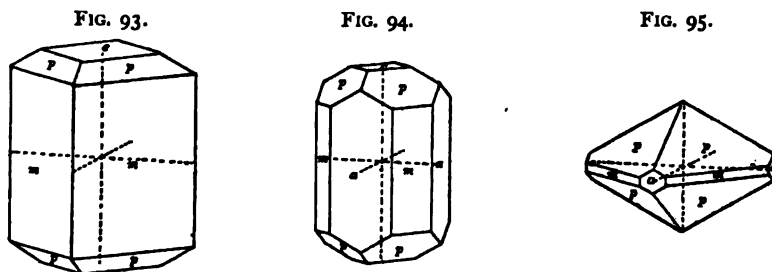
By considering the forms of each substance separately, a clear idea is obtained as to the pyramidal forms, which vary in shape and angle with the relative lengths of  $mc$  and  $a$ , although as ex-



plained, p. 36, the pyramids which occur upon crystals of *any one substance* are definitely related in axial intercepts and usually very limited in number.

*Zircon*. — Axes  $a : c = 1 : 0.640$ .

Fig. 89 shows the common association of unit pyramid  $p$  and unit prism  $m$ . In Fig. 90 these two forms are combined with the prism of the second order  $a$  and in Fig. 91 with the pyramid  $u = (a : a : 3c)$ ;  $\{331\}$ . Fig. 92 shows the union of second order prism, unit pyramid and ditetragonal pyramid  $x = (a : 3a : 3c)$ ;  $\{311\}$ .



*Vesuvianite*. — Axes  $a : c = 1 : 0.537$ .

The unit pyramid in vesuvianite is only a little flatter than in zircon, hence there is little difference between the pyramid angles

in Fig. 89 and Fig. 95. The relative development of faces, or "crystal habit," is, however, markedly different.

Fig. 93 shows the combination of unit pyramid  $p$ , unit prism  $m$  and basal pinacoid  $c$ , Fig. 94 shows these three forms combined with the prism of the second order  $a$  and Fig. 95 shows the two prisms and the unit pyramid.

FIG. 96.

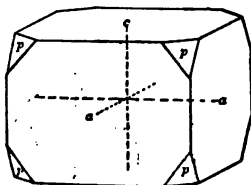


FIG. 97.

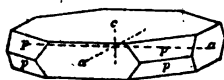


FIG. 98.

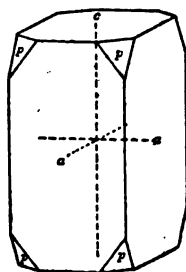
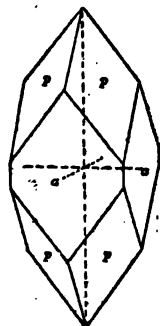


FIG. 99.



*Apophyllite*.—Axes  $a : c = 1 : 1.252$ .

As indicated by the ratios of  $a$  to  $c$  the unit pyramid of this mineral is much more acute than in zircon and vesuvianite, this is clearly apparent in Fig. 99. The figures also illustrate well the possibility of great differences in habit without any difference in occurring forms, thus Figs. 96, 97 and 98 are all combinations

FIG. 100.

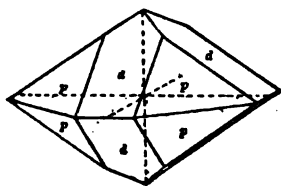
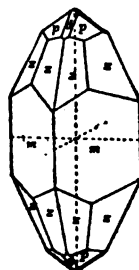


FIG. 101.



the unit pyramid  $p$ , basal pinacoid  $c$  and second order prism  $a$ . In Fig. 99 the basal pinacoid does not occur.

*Cassiterite*.—Axes  $a : c = 1 : 0.6723$ .

In this the ratio of  $a$  to  $c$  is closely as in zircon but the common

association is now the unit pyramid  $p$  with the second order pyramid  $d$  as shown in Fig. 100.

In Fig. 101 these forms occur with a ditetragonal pyramid  $z = (a : \frac{3}{2}a : 3c) \{321\}$  and the unit prism  $m$ .

#### OTHER CLASSES OF SYMMETRY IN THE TETRAGONAL SYSTEM.

Six other classes of symmetry have been distinguished in the Tetragonal system :

9. CLASS OF THE THIRD ORDER BISPHENOID.—With one axis of two-fold symmetry. No examples are known.

10. CLASS OF THE HEMIMORPHIC PYRAMID OF THIRD ORDER.—With one axis of four-fold symmetry. Example—Wulfenite.

11. SCALENOHEDRAL CLASS.—With two planes of symmetry at  $90^\circ$  intersecting in an axis of two-fold symmetry. Also two axes of two-fold symmetry midway between the planes. Examples—Chalcopyrite and stannite.

12. TRAPEZOHEDRAL CLASS.—Without planes of symmetry, but with one four-fold axis at  $90^\circ$  to four two-fold axes. No examples among minerals are known, the type salt is nickel sulphate,  $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ .

13. CLASS OF THE TETRAGONAL PYRAMID OF THIRD ORDER.—With one horizontal plane of symmetry and one vertical axis of four-fold symmetry. Examples—Scheelite, wernerite and stolzite.

14. HEMIMORPHIC CLASS.—With four planes of symmetry intersecting in an axis of four-fold symmetry. No examples among minerals are known. Examples in salts are Iodosuccinimid,  $\text{C}_4\text{H}_4\text{O}_2\text{NI}$ , and Hydrus Silver Fluoride,  $\text{AgFH}_2\text{O}$ .



## CHAPTER VI.

### HEXAGONAL SYSTEM.\*

ALL hexagonal crystals are conveniently referred to *four* crystallographic axes, one vertical and at right angles to the others, three horizontal and interchangeable and at sixty degrees to each other.

Bravais proved that if the horizontal axes were considered in the order shown in Fig. 102, the indices for any face with respect to these axes were always such that any one was equal to the sum of the other two with its sign reversed. It is therefore easiest to note the indices with respect to the first two axes and add these and change the sign for the third.

For *type* symbols reserve *l* for the vertical axis and use *h* for axis with shorter intercept.

#### RHOMBOHEDRAL DIVISION, SCALENOHEDRAL CLASS.

No. 13. Rhombohedral Hemihedry, *Liebsch.* No. 19. Rhombohedral Group, *Dana*

This most important group in the hexagonal system includes the crystals of such minerals as calcite, corundum, hematite and chabazite. All crystals in the class are symmetrical to three planes

FIG. 102.

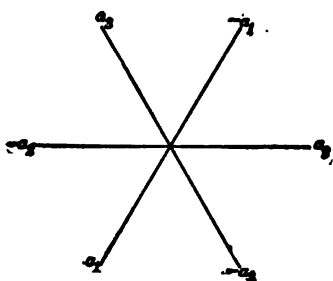


FIG. 103.

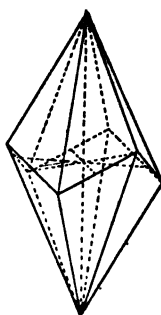
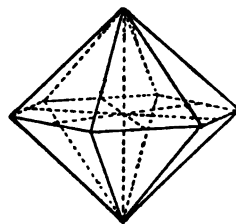


FIG. 104.



at  $60^\circ$  to each other. Their intersection is the three-fold axis and there are three two-fold axes diagonal to the planes.

\* Also called Rhombohedral, Sechsgliedrige, Drei-und-Einaxige and Monotrimetric.

### Choosing Crystallographic Axes.

The axes of symmetry are chosen. The three-fold axis is the vertical  $z$ , the others are horizontal and one of them  $a_1$ , Fig. 102, is placed from left to right, and one  $a_2$  is considered to be negative in front, positive behind.

### Tabulation of the Seven Type Forms.

| NAME.                            | FACES. | WEISS.                               | MILLER.                                |
|----------------------------------|--------|--------------------------------------|--|
| Each face oblique to $z$ .       |        |                                      |  |
| 1. SCALENOHEDRON.                | 12     | $a : na : pa : mc$                   | $\{hkl\}$                              |
| 2. HEXAG. PYRAMID 2° ORDER.      | 12     | $2a : 2a : a : mc$                   | $\{h \cdot h \cdot 2\bar{h} \cdot l\}$ |
| 3. RHOMBOHEDRON 1° ORDER.        | 6      | $a : \infty a : a : mc$              | $\{h\bar{o}hl\}$                       |
| Each face perpendicular to $z$ . |        |                                      |  |
| 4. BASAL PINACOID.               | 2      | $\infty a : \infty a : \infty a : c$ | $\{0001\}$                             |
| Each face parallel to $z$ .      |        |                                      |  |
| 5. DIHEXAGONAL PRISM.            | 12     | $a : na : pa : \infty c$             | $\{hk10\}$                             |
| 6. HEXAG. PRISM 2° ORDER.        | 6      | $2a : 2a : a : \infty c$             | $\{1120\}$                             |
| 7. HEXAG. PRISM 1° ORDER.        | 6      | $a : \infty a : a : \infty c$        | $\{10\bar{1}0\}$                       |

### Description of the Type Forms.

1. SCALENOHEDRON. —  $a : na : pa^* : mc$ ;  $\{hkl\}$ .

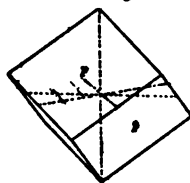
Twelve faces, each cutting all the axes. In the ideal form the faces are scalene triangles. The adjacent polar edges are necessarily unequal.

Fig. 103. Also the faces  $v$ , Figs. 113 and 116.

2. HEXAGONAL PYRAMID OF SECOND ORDER. —  $2a : 2a : a : mc$ ;  $\{h \cdot h \cdot 2\bar{h} \cdot l\}$ .

Twelve faces, Fig. 104, each cutting one horizontal axis at a certain distance, the others at *twice* † that distance, and the vertical axis at some distance *not* simply proportionate to the rest. In the ideal form the faces are isosceles triangles.

FIG. 105.



3. RHOMBOHEDRON OF FIRST ORDER. —  $a : \infty a : a : mc$ ;  $\{h\bar{o}hl\}$ .

Six faces, each cutting two basal axes at equal distances, parallel to the third and cutting the vertical. In the ideal forms the faces are rhombs, Figs. 105, 109, 110 and 114.

4. BASAL PINACOID. —  $\infty a : \infty a : \infty a : c$ ;  $\{0001\}$ .

Two faces each parallel to the three horizontal axes. The faces  $c$  of Figs. 106 to 108.

\* It may be shown that in the Weiss symbols the numerical value of  $p = n/n(-1)$  and in the Miller symbols that  $i = -(h + k)$ .

† Easily shown by the angles in a horizontal section.

5. DIHEXAGONAL PRISM. —  $a : na : pa : \infty c$ ;  $\{hk10\}$ .

Twelve faces each parallel to the vertical axis and cutting all horizontal axes at unequal distances, simple multiples of each other, Fig. 106, shows  $s = (a : \frac{3}{2}a : 3a : \infty c)$ ;  $\{21\bar{3}0\}$ .

6. HEXAGONAL PRISM OF SECOND ORDER. —  $2a : 2a : a : \infty c$ ;  $\{11\bar{2}0\}$ .

Six faces each parallel the vertical axis and cutting one horizontal

FIG. 106.

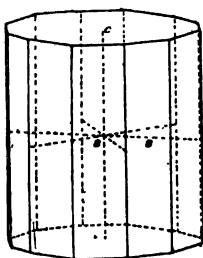


FIG. 107.

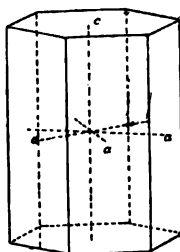
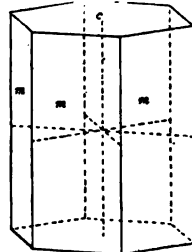


FIG. 108.



axis at a certain distance, the other two at *twice* that distance. The faces  $a$ , Figs. 107 and 121.

7. HEXAGONAL PRISM OF FIRST ORDER. —  $a : \infty a : a : \infty c$ ;  $\{10\bar{1}0\}$ .

Six faces each parallel to the vertical and one horizontal axis and cutting the other two at equal distances. The faces  $m$ , Figs. 108, 112 and 115.

**Combinations in the Scalenohedral Class.**

*Calcite.* — Axes  $a : c = 1 : 0.854$ .

Figs. 109 to 116 represent the more common of the extremely numerous forms of calcite. Rhombohedrons and scalenohedrons predominate. The rhombohedrons shown are  $p$  the unit, Fig. 109,  $e$  the negative form of  $a : \infty a : a : \frac{1}{2}c$ ;  $\{10\bar{1}2\}$ ; Fig. 110;  $f$  the negative form of  $a : \infty a : a : 2c$ ;  $\{20\bar{2}1\}$ , Fig. 114; and  $q$  the positive form of  $a : \infty a : a : 16c$ ;  $\{16.0.\bar{1}6.1\}$ ; Fig. 111.

Two scalenohedrons only are shown,  $v = (\frac{3}{2}a : 3a : a : 3c)$ ;  $\{21\bar{3}1\}$ ; Fig. 113, and  $w = (\frac{4}{3}a : 4a : a : \frac{4}{3}c)$ ;  $\{31\bar{4}5\}$ ; Fig. 116.

The rhombohedron  $e$  occurs more frequently than the unit and is shown in combination with the rhombohedron  $q$  in Fig. 111 and with the prism  $m$  in Figs. 112 and 115.

The unit rhombohedron is shown in combination with the scalenohedron  $v$  in Fig. 113, and with the two scalenohedrons  $v$  and  $w$  in Fig. 116.

FIG. 109.

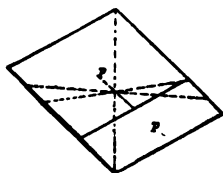


FIG. 110.



FIG. 111.

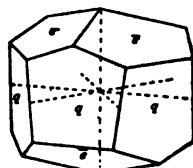


FIG. 112.

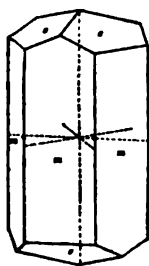


FIG. 113.

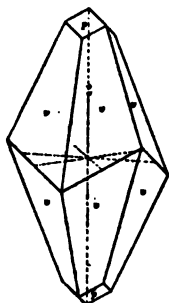
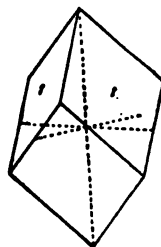


FIG. 114.



*Hematite.* — Axes  $a : c = 1 : 1.365$ .

Fig. 119 shows the unit rhombohedron  $p$  with the basal pinacoid  $c$  and the second order pyramid  $n = (2a : 2a : a : \frac{1}{2}c) ; \{2243\}$ ;

FIG. 115.

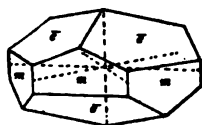


FIG. 116.

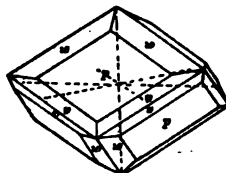


Fig. 117 shows the same except that the basal pinacoid is replaced by the rhombohedron  $g = (a : \infty a : a : \frac{1}{2}c) ; \{10\bar{1}4\}$ ; and Fig. 118 shows the two rhombohedrons  $p$  and  $g$ .

FIG. 117.

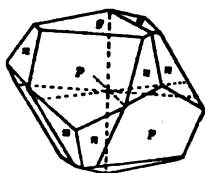


FIG. 118.

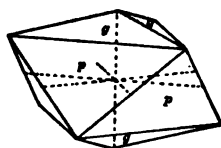
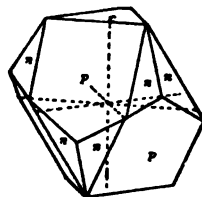


FIG. 119.



*Corundum.* — Axes  $a : c = 1 : 1.363$ .

The unit forms of hematite and corundum are practically identical,

but the combinations and habit are very different. Fig. 120 shows a second order pyramid  $n = (2a : 2a : a : \frac{1}{2}c)$ ;  $\{22\bar{4}3\}$ . Fig. 121 shows this and two other second order forms  $o = (2a : 2a : a : \frac{1}{2}c)$ ;  $\{44\bar{8}3\}$ ; and  $a = (2a : 2a : a : \infty c)$ ;  $\{11\bar{2}0\}$ ; and a rhombohedron  $f = (a : \infty a : a : 2c)$ ;  $\{2021\}$ . Fig. 122 shows a second order pyramid  $w = (2a : 2a : a : 2c)$ ;  $\{11\bar{2}1\}$ ; with the unit rhombohedron  $p$  and the basal pinacoid  $c$ .

FIG. 120.

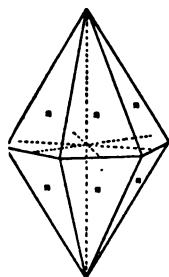


FIG. 121.

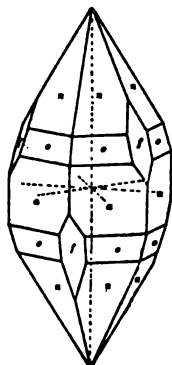
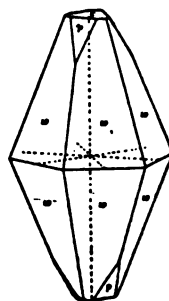


FIG. 122.



#### RHOMBOHEDRAL DIVISION, HEMIMORPHIC CLASS.\* 20.

No. 14. Second Hemimorphic Tetartohedry, *Liebsch.* No. 20. Rhombohedral Hemimorphic Group, *Dana.*

The common mineral, tourmaline, and the ruby silvers, proustite and pyrrargyrite, occur in forms showing different groupings of

FIG. 123.

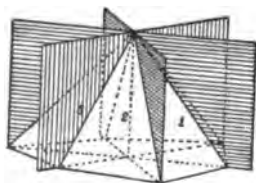
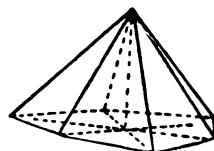


FIG. 124.



faces at opposite ends of the vertical axis. That is the forms are symmetrical to a three-fold axis and to three planes through this at  $60^\circ$  to each other, Fig. 123.

#### Choosing Crystallographic Axes.

The three-fold axis is taken as the vertical ( $c$ ) axis; the others are diagonal to the planes of symmetry.

\* The forms differ so markedly from those of the preceding and following class that it has been thought wise to describe them in detail.

## Tabulation of Seven Type Forms.

| NAME.                                | FACES. | WEISS.                               | MILLER.                          |
|--------------------------------------|--------|--------------------------------------|----------------------------------|
| Each face oblique to $c$ .           |        |                                      |                                  |
| 1. HEM. DITRIGONAL PYRAMID.          | 6      | $a : na : pa : mc$                   | $\{hkl\}$                        |
| 2. HEM. HEX. PYRAM. SECOND ORDER.    | 6      | $2a : 2a : a : mc$                   | $\{h \cdot h \cdot 2h \cdot l\}$ |
| 3. HEM. TRIGONAL PYRAM. FIRST ORDER. | 3      | $a : \infty a : a : mc$              | $\{hoh\}$                        |
| Each face perpendicular to $c$ .     |        |                                      |                                  |
| 4. BASAL PLANE.                      | 1      | $\infty a : \infty a : \infty a : c$ | $\{0001\}$                       |
| Each face parallel to $c$ .          |        |                                      |                                  |
| 5. DITRIGONAL PRISM.                 | 6      | $a : na : pa : \infty c$             | $\{hkio\}$                       |
| 6. HEXAG. PRISM SECOND ORDER.        | 6      | $2a : 2a : a : \infty c$             | $\{11\bar{2}0\}$                 |
| 7. TRIGONAL PRISM FIRST ORDER.       | 3      | $a : \infty a : a : \infty c$        | $\{10\bar{1}0\}$                 |

## Description of the Type Forms.

1. HEMIMORPH. DITRIGONAL PYRAMID.— $a : na : pa : mc$ ;  $\{hkl\}$ .

Six faces, Fig. 124, each cutting all horizontal axes at simply related distances and all cutting the vertical axis.

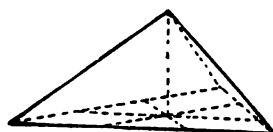
2. HEMIMORPH. HEXAG. PYRAMID 2° ORDER.— $2a : 2a : a : mc$ ;  $\{h \cdot h \cdot 2h \cdot l\}$ .

Six faces, Fig. 125, each cutting one horizontal axis at a certain distance, the others at *twice* that distance, and the vertical axis at a distance *not* simply proportionate.

FIG. 125.



FIG. 126.



3. HEMIMORPH. TRIGONAL PYRAMID 1° ORDER.— $a : \infty a : a : mc$ ;  $\{hoh\}$ .

Three faces, Fig. 126, each parallel to one horizontal axis, cutting the other two at equal distances, and the vertical axis at some distance *not* simply proportionate.

4. THE BASAL PLANE.— $\infty a : \infty a : \infty a : c$ ;  $\{0001\}$ .

One face parallel to the basal axes.

5. DITRIGONAL PRISM.— $a : na : pa : \infty c$ ;  $\{hkio\}$ .

Six faces, Fig. 127, each parallel to the vertical axis and cutting all horizontal axes at unequal distances simple multiples of each other.

6. HEX. PRISM OF SECOND ORDER.— $2a : 2a : a : \infty c$ ;  $\{h \cdot h \cdot 2h \cdot 0\}$ .

Previously described. See Fig. 107.

7. TRIGONAL PRISM OF FIRST ORDER.— $a : \infty a : a : \infty c$ ;  $\{10\bar{1}0\}$ .

Three vertical faces, each parallel to one horizontal axis and intersecting the others at equal distances from the center, Fig. 128.

FIG. 127.

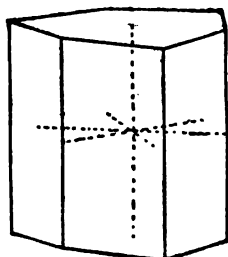
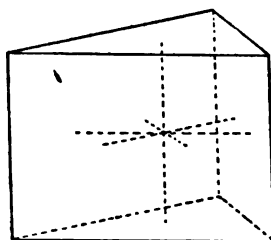


FIG. 128.



### Combinations in the Hemimorphic Class.

*Tourmaline.*—Axes  $a : c = 1 : 0.447$ .

Fig. 129 shows the first order trigonal prism  $m$ , the second order hexagonal prism  $a$ ; at the upper end the trigonal pyramids of first order  $p = (a : \infty a : a : c)$ ;  $\{10\bar{1}1\}$ ; and  $f = (a : \infty a : a : 2c)$ ;  $\{2021\}$ ; but at the lower end the trigonal pyramid  $p$  only. Fig. 130 shows  $m$ ,  $p$  and  $a$ , but does not so evidently reveal the hemimorphic symmetry. Fig. 131 again shows  $m$  and  $a$  central; with at one end  $p$  and at the other  $f$ .

FIG. 129.

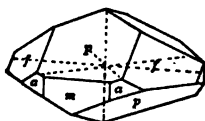


FIG. 130.

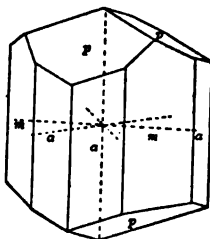
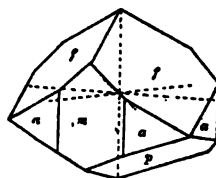


FIG. 131.



### OTHER CLASSES OF SYMMETRY IN THE RHOMBOHEDRAL DIVISION.

- In each there is an axis of three-fold symmetry.

#### 16. CLASS OF HEMIMORPH. TRIGONAL PYRAMID $3^\circ$ ORDER.

The three-fold axis. No planes or center of symmetry. Example sodium periodate,  $\text{NaIO}_4 \cdot 3\text{H}_2\text{O}$ .

#### 17. CLASS OF RHOMBOHEDRON $3^\circ$ ORDER.

The three-fold axis and center of symmetry. Examples—Dolomite, ilmenite, willemite, phenacite, diopase.

## 18. CLASS OF TRIGONAL TRAPEZOHEDRON.

The three-fold axis and three two-fold axes of symmetry at  $90^\circ$  thereto. Examples—Quartz, cinnabar.

 19. CLASS OF TRIGONAL PYRAMID  $3^\circ$  ORDER.

The three-fold axis and one plane of symmetry at  $90^\circ$  thereto. No examples known.

## 22. CLASS OF DITRIGONAL PYRAMID.

The three-fold axis, three planes at  $60^\circ$  and one at  $90^\circ$  to the three. No examples known.

## HEXAGONAL DIVISION. CLASS OF DIHEXAGONAL PYRAMID. 27.

No. 6. Holohedral, *Liebsch*. No. 13. Normal Group, *Dana*.

A few minerals, notably beryl, crystallize in forms symmetrical to one horizontal plane and to six vertical planes at thirty degrees to each other and to one six-fold and six two-fold axes which are the lines of intersection of these planes, Fig. 132.

## Choosing Crystallographic Axes.

The six-fold axis is chosen as the vertical  $c$ , the two-fold axes as the horizontal axes  $a$ , one of which is conventionally placed from left to right.

## Tabulation of the Seven Type Forms.

|                                       | NAME.                           | FACES. | WEISS.                               | MILLER.                 |
|---------------------------------------|---------------------------------|--------|--------------------------------------|-------------------------|
| Each face oblique to $\angle$ .       |                                 |        |                                      |                         |
| 1.                                    | DIHEXAGONAL PYRAMID.            | 24     | $a : na : pa : mc$                   | $\{hkl\}$               |
| 2.                                    | HEXAG. PYRAMID $2^\circ$ ORDER. | 12     | $2a : 2a : a : mc$                   | $\{h\bar{h}2h\bar{l}\}$ |
| 3.                                    | HEXAG. PYRAMID $1^\circ$ ORDER. | 12     | $a : \infty a : a : mc$              | $\{h0h\bar{l}\}$        |
| Each face perpendicular to $\angle$ . |                                 |        |                                      |                         |
| 4.                                    | BASAL PINACOID.                 | 2      | $\infty a : \infty a : \infty a : c$ | $\{0001\}$              |
| Each face parallel to $\angle$ .      |                                 |        |                                      |                         |
| 5.                                    | DIHEXAGONAL PRISM.              | 12     | $a : na : pa : \infty c$             | $\{h\bar{h}k0\}$        |
| 6.                                    | HEXAG. PRISM $2^\circ$ ORDER.   | 6      | $2a : 2a : a : \infty c$             | $\{11\bar{2}0\}$        |
| 7.                                    | HEXAG. PRISM $1^\circ$ ORDER.   | 6      | $a : \infty a : a : \infty c$        | $\{10\bar{1}0\}$        |

## Description of the Type Forms.

1. DIHEXAGONAL PYRAMID.— $a : na : pa : mc$ ;  $\{hkl\}$ .

Twenty-four faces, Fig. 133, each of which cuts the three horizontal axes at unequal distances, simple multiples of each other; and the vertical axis at some distance *not* simply related to the others. In the ideal form the faces are scalene triangles.



2. HEXAGONAL PYRAMID OF SECOND ORDER. — See Fig. 104.

3. HEXAGONAL PYRAMID OF FIRST ORDER. —  $a : \infty a : a : mc ; \{h\bar{o}hl\}$ .

Twelve faces, Fig. 134, each parallel to one horizontal axis, cutting the others at equal distances, and the vertical axis at some distance *not* simple proportionate. In ideal forms the faces are isosceles triangles.

4. BASAL PINACOID. — The faces  $c$  of Figs. 135 to 137.

5. DIHEXAGONAL PRISM. — See Fig. 106.

FIG. 132.

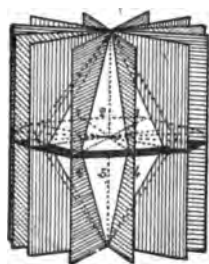


FIG. 133.

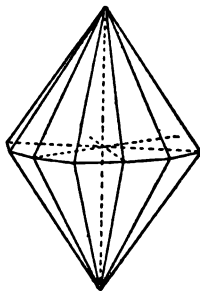
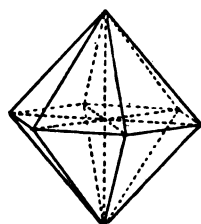


FIG. 134.



6. HEXAGONAL PRISM OF SECOND ORDER. — See Fig. 107.

7. HEXAGONAL PRISM OF FIRST ORDER. — See Fig. 108 or the faces  $m$  of Figs. 135 to 137.

**Combinations in the Class of Dihexagonal Pyramid.**

*Beryl.* — Axes  $a : c = 1 : 0.499$ .

FIG. 135.

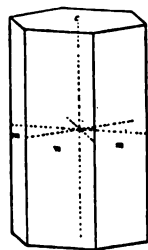


FIG. 136.

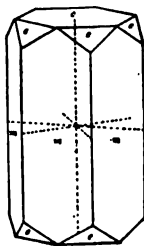


FIG. 137.

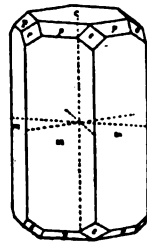


Fig. 135 shows the prism of first order  $m$  and basal pinacoid  $c$ ; in Fig. 136 the second order pyramid  $e = (2a : 2a : a : 2c) ; \{11\bar{2}1\}$ ; occurs and in Fig. 137 the unit pyramid  $p$  is also present.

**OTHER CLASSES IN THE HEXAGONAL DIVISION.**

Each with an axis of six-fold symmetry.

23. CLASS OF THIRD ORDER HEMIMORPHIC PYRAMID.—The six-fold axis only. Example—nephelite.

24. CLASS OF HEXAGONAL TRAPEZOHEDRON. — The six-fold axis and six 2-fold axes of symmetry at  $90^\circ$  thereto. Example—Barium-antimonyl dextro-tartrate potassium nitrate,  $\text{Ba}(\text{SbO})_2 \cdot (\text{C}_4\text{H}_4\text{O}_6)_2 \cdot \text{KNO}_3$ .

25. CLASS OF THIRD ORDER HEXAGONAL PYRAMID. — The six-fold axis and a plane of symmetry at  $90^\circ$  thereto. Examples—Apatite, pyromorphite, mimetite, vanadinite.

26. CLASS OF HEMIMORPHIC DIHEXAGONAL PYRAMID. — The six-fold axis and six planes of symmetry at  $30^\circ$  to each other intersecting therein. Example—Iodyrite.

## CHAPTER VII.

### ISOMETRIC SYSTEM.

THE Isometric \* system includes all crystal forms which can be referred to three interchangeable axes at right angles to each other, that is axes about which there are equal numbers of faces grouped with corresponding faces at the same angles.

Five classes are distinguished, of which three include nearly all known isometric minerals.

#### HEXOCTAHEDRAL CLASS. 32.

No. 1. Holohedral, *Liebsch.* No. 1. Normal Group, *Dana.*

#### Symmetry of the Class.

There are three planes of symmetry, Fig. 138, parallel to cube faces, and six planes through diagonally opposite cube edges. There are also, Fig. 139, three four-fold, four three-fold and six two-fold axes of symmetry.

#### Choosing Crystallographic Axes.

The three axes of four-fold symmetry are chosen as the crystallographic axes. Usually one is assumed to be vertical and one to extend from left to right.

#### Tabulation of the Seven Type Forms.

| NAME.                           | FACES. | WEISS.                    | MILLER.   |
|---------------------------------|--------|---------------------------|-----------|
| Each face intersects all axes.  |        |                           |           |
| 1. HEXOCTAHEDRON.               | 48     | $a : na : ma$             | $\{hkl\}$ |
| 2. TRAPEZOHEDRON.               | 24     | $a : ma : ma$             | $\{hkk\}$ |
| 3. TRISOCTAHEDRON.              | 24     | $a : a : ma$              | $\{hhl\}$ |
| 4. OCTAHEDRON.                  | 8      | $a : a : a$               | $\{111\}$ |
| Each face parallel to one axis. |        |                           |           |
| 5. DODECAHEDRON.                | 12     | $a : a : \infty a$        | $\{110\}$ |
| 6. TETRAHEXAHEDRON.             | 24     | $a : na : \infty a$       | $\{hko\}$ |
| Each face parallel to two axes. |        |                           |           |
| 7. CUBE.                        | 6      | $a : \infty a : \infty a$ | $\{100\}$ |

#### Description of the Type Forms.

I. HEXOCTAHEDRON. —  $a : na : ma ; \{hkl\}$ .

---

\* Also called Tesseral, Tessular, Regular, Cubic and Monometric.

Forty-eight faces each cutting the three axes in three different, but simply proportionate distances. In the ideal forms the faces are scalene triangles. Fig. 140 shows  $a : \frac{2}{3}a : 3a$ ;  $\{321\}$ .

FIG. 138.

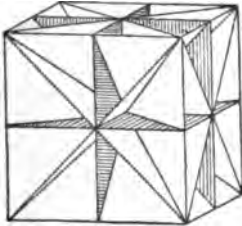
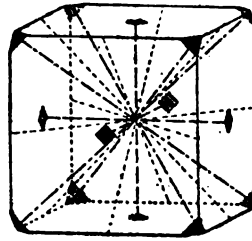


FIG. 139.



The small black squares and triangles indicate axes of four-fold and three-fold symmetry respectively.

2. TRAPEZOHEDRON. —  $a : ma : ma$ ;  $\{hkk\}$ .

Twenty-four faces, each cutting two axes equally and the third in some shorter distance bearing a simple ratio to the others. In

FIG. 140.

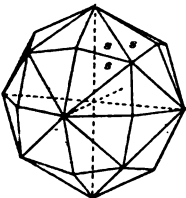


FIG. 141.

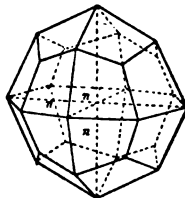
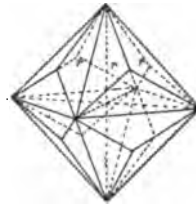


FIG. 142.

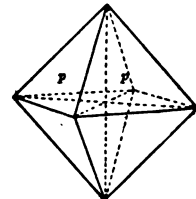


the ideal form the faces are trapeziums. Fig. 141 shows  $a : 2a : 2a$ ;  $\{211\}$ .

3. TRISOCTAHEDRON. —  $a : a : ma$ ;  $\{hhl\}$ .

Twenty-four faces, each cutting two axes at equal distances, the third axes at some longer distance a simple multiple of the others. In the ideal forms the faces are isosceles triangles. Fig. 142 shows  $r = (a : a : 2a)$ ;  $\{221\}$ .

FIG. 143.



4. THE OCTAHEDRON. —  $a : a : a$ ;  $\{111\}$ .

Eight faces, Fig. 143, each cutting the three axes at equal distances. In the ideal form the faces are equilateral triangles.

5. TETRAHEDRON. —  $a : na : \infty a$ ;  $\{hko\}$ .

Twenty-four faces, Fig. 144, each parallel to one axis and cut-

ting the other two unequally in distances bearing a simple ratio to each other. In the ideal forms the faces are equal isosceles triangles. Fig. 144 shows  $a : 2a : \infty a$ ;  $\{210\}$ .

FIG. 144.

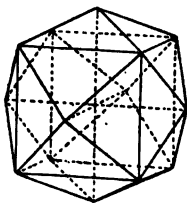


FIG. 145.

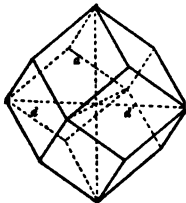
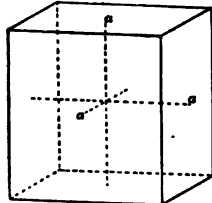


FIG. 146.



6. THE DODECAHEDRON. —  $a : a : \infty a$ ;  $\{110\}$ .

Twelve faces, Fig. 145, each parallel to one axis and cutting the others at equal distances. In the ideal form each face is a rhombus.

7. THE CUBE. —  $a : \infty a : \infty a$ ;  $\{100\}$ .

FIG. 147.

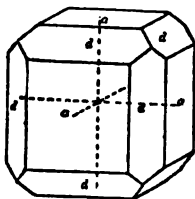


FIG. 148.

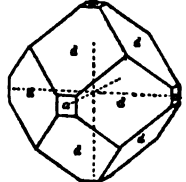
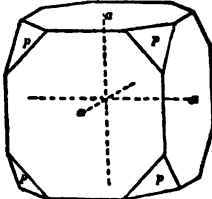


FIG. 149.



Six faces, Fig. 146, each parallel to two axes. In the ideal forms the faces are squares.

**Combinations in the Hexoctahedral Class.**

The most frequently occurring forms are the cube  $a$ , the octahe-

FIG. 150.

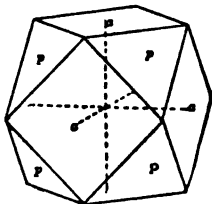


FIG. 151.

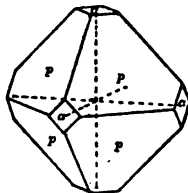
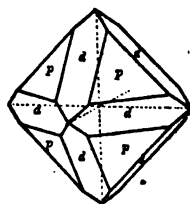


FIG. 152.



dron  $p$ , the dodecahedron  $d$ , and the trapezohedron  $n = (a : 2a : 2a)$ ;  $\{211\}$ . The other forms usually occur modifying these.

The cube  $a$  and dodecahedron  $d$ , Figs. 147, 148, are combined in crystals of fluorite, argentite and cuprite. The cube and octa-

hedron  $p$ , Figs. 149, 150 and 151, are very frequently combined in fluorite, galenite, silver, sylvite and many other minerals. The octahedron,  $p$ , and dodecahedron,  $d$ , Figs. 152 and 153, are frequently found in spinel, magnetite, franklinite and cuprite, while

FIG. 153.

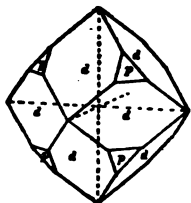


FIG. 154.

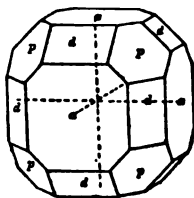
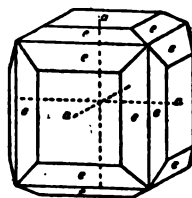


FIG. 155.



the three together, cube, dodecahedron and octahedron, Fig. 154, occur in smaltite, galenite and fluorite. The tetrahexahedron  $e = (a : 2a : \infty a) ; \{210\}$ ; is found with the cube in fluorite, Fig. 155.

FIG. 156.

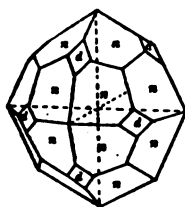


FIG. 157.

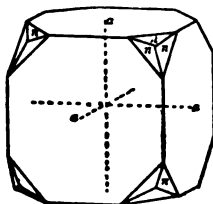
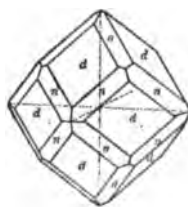


FIG. 158.



The trapezohedron  $n = (a : 2a : 2a) ; \{211\}$ ; is common in analcite, garnet and amalgam, either combined with the dodecahedron, Figs. 156 and 158 or with the cube, Fig. 157.

FIG. 159.

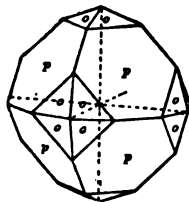


FIG. 160.

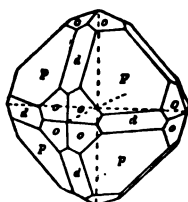
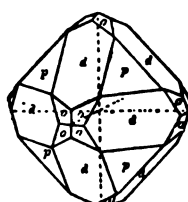


FIG. 161.



Another trapezohedron  $o = (a : 3a : 3a) ; \{311\}$ ; occurs in spinel and magnetite either with the octahedron, Fig. 159, or with both octahedron and dodecahedron, Figs. 160 and 161.

The trisoctahedron  $r = (a : a : 2a) ; \{221\}$ ; occasionally occurs, especially in galenite and magnetite, combined with octahedron

and dodecahedron, Fig. 162. The hexoctahedron  $t = (a : 2a : 4a)$ ;  $\{421\}$ ; occurs modifying cubes of fluorite, Fig. 163, and another hexoctahedron  $s = (a : \frac{3}{2}a : 3a)$ ;  $\{321\}$ ; occurs in garnet, Fig. 164.

FIG. 162.

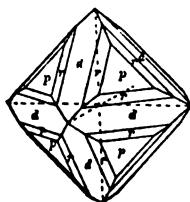


FIG. 163.

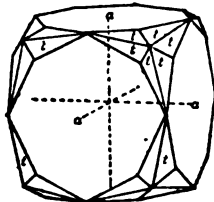


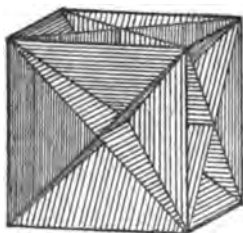
FIG. 164.



### HEXTETRAHEDRAL CLASS. 31.

No. 2. Tetrahedral Hemihedry, *Liebsch*. No. 3. Tetrahedral Group, *Dana*.

FIG. 165.



In this class of isometric forms, to which crystals of the diamond, tetrahedrite, sphalerite and boracite belong, the shaded planes of Fig. 138 are no longer planes of symmetry, and the symmetry is restricted to the diagonal planes shown in Fig. 165 and to the four three-fold and three two-fold axes formed by their intersection.

#### Choosing Crystallographic Axes.

The three axes of two-fold symmetry are chosen as the crystallographic axes.

#### Tabulation of the Seven Type Forms.

| NAME.                           | FACES. | WEISS.                    | MILLER.   |
|---------------------------------|--------|---------------------------|-----------|
| Each face intersects all axes.  |        |                           |           |
| 1. HEXTETRAHEDRON.              | 24     | $a : na : ma$             | $\{hkl\}$ |
| 2. TRISTETRAHEDRON.             | 12     | $a : ma : ma$             | $\{hkk\}$ |
| 3. DELTOHEDRON.                 | 12     | $a : a : ma$              | $\{hhl\}$ |
| 4. TETRAHEDRON.                 | 4      | $a : a : a$               | $\{111\}$ |
| Each face parallel to one axis. |        |                           |           |
| 5. TETRAHXAHEDRON.              | 24     | $a : na : \infty a$       | $\{hko\}$ |
| 6. DODECAHEDRON.                | 12     | $a : a : \infty a$        | $\{110\}$ |
| Each face parallel to two axes. |        |                           |           |
| 7. CUBE.                        | 6      | $a : \infty a : \infty a$ | $\{100\}$ |

#### Descriptions of the Type Forms.

I. HEXTETRAHEDRON. —  $a : na : ma$ ;  $\{hkl\}$ .

Twenty-four faces each cutting the three axes in three different,

but simply proportionate, distances. In the ideal forms the faces are scalene triangles. Fig. 166.

2. TRISTETRAHEDRON. —  $a : ma : ma$ ;  $\{hkk\}$ .

Twelve faces, Fig. 167, each cutting two axes equally and the

FIG. 166.

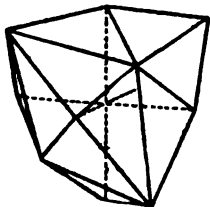
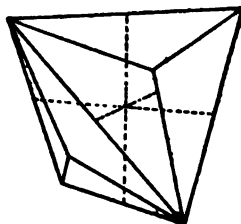


FIG. 167.



third in some shorter distance bearing a simple ratio to the others. In the ideal form the faces are isosceles triangles.

3. DELTOHEDRON. —  $a : a : ma$ ;  $\{hhl\}$ .

Twelve faces, each cutting two axes equally and the third in some longer distance a simple multiple of the others. In the ideal form the faces are trapeziums. Fig. 168 shows  $r = (a : a : 2a)$ ;  $\{221\}$ .

FIG. 168.

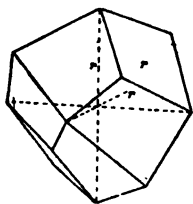
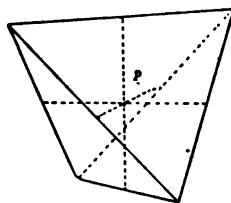


FIG. 169.



4. THE TETRAHEDRON. —  $a : a : a$ ;  $\{111\}$ .

Four faces, Fig. 169, each cutting the three axes at equal distances. In the ideal form the faces are equilateral triangles.

5. TETRAHEXAEDRON. — Fig. 144.

6. THE DODECAHEDRON. — Fig. 145.

7. THE CUBE. — Fig. 146.

#### Combinations in the Hextetrahedral Class.

The characteristics of the crystals of this group are best shown in combinations of forms, since the simple forms are comparatively rare and the predominating form is frequently the cube.

The combination of the positive and negative tetrahedrons, Fig. 170 occurs in crystals of sphalerite and tetrahedrite. The combi-



nation of the tetrahedron and cube  $a$ , Figs. 171 and 172, is common in boracite and pharmacosiderite. The tetrahedron with the dodecahedron  $d$ , Fig. 173, occurs in tetrahedrite, and with both cube and dodecahedron, Fig. 174, in boracite.

FIG. 170.

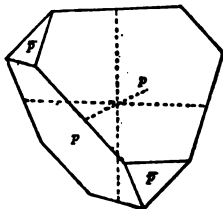


FIG. 171.

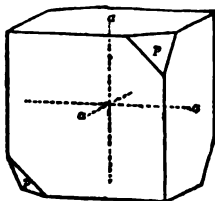
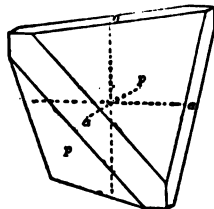


FIG. 172.



Figs. 175 and 176 are crystals of tetrahedrite. In Fig. 175 the negative form of  $n = (a : 2a : 2a) ; \{211\}$  occurs and in Fig. 176 the positive form of  $n$  with the dodecahedron  $d$ .

FIG. 173.

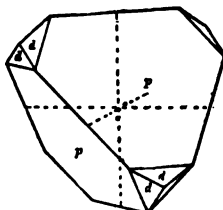


FIG. 174.

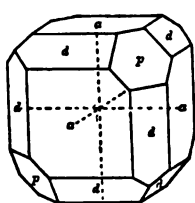


FIG. 175.

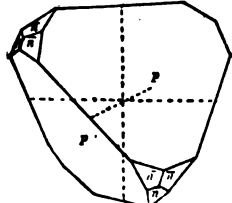


Fig. 177 includes the dodecahedron  $d$ , the deltohedron  $r = (a : a : 2a) ; \{221\}$ ; and the tristetrahedrons  $o = (a : 3a : 3a) ; \{311\}$ ; and  $n = (a : 2a : 2a) ; \{211\}$ ; Fig. 178 shows the hextetrahedron  $s$

FIG. 176.

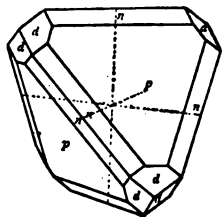


FIG. 177.

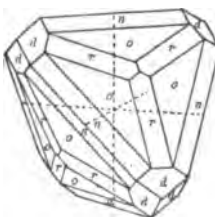
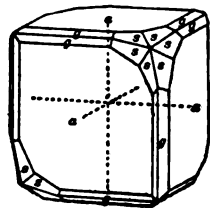


FIG. 178.



$= (a : \frac{3}{2}a : 3a) ; \{321\}$ ; combined with the cube and tetrahexahedron  $g = (a : \frac{3}{2}a : \infty a) ; \{320\}$ .

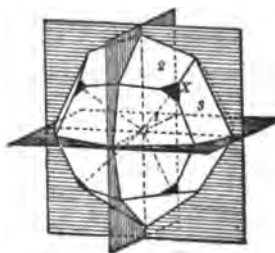
## CLASS OF THE DIPLOID. 30.

No. 4. Pentagonal Hemihedry, *Liebsch.* No. 2. Pyritohedral Group, *Dana.*

## Symmetry of the Class.

Crystals of the common mineral pyrite and of the minerals cobaltite and smaltite are symmetrical to three planes at right angles and to three axes of two-fold and four axes of three-fold symmetry, as shown in Fig. 179.

FIG. 179.



## Choosing Crystallographic Axes.

The three axes of two-fold, symmetry are chosen as the crystallographic axes.

## Tabulation of the Seven Type Forms.

| NAME.                              | FACES. | WEISS.                    | MILLER.   |
|------------------------------------|--------|---------------------------|-----------|
| Each face intersects all the axes. |        |                           |           |
| 1. DIPLOID.                        | 24     | $a : na : ma$             | $\{hkl\}$ |
| 2. TRAPEZOHEDRON.                  | 24     | $a : ma : ma$             | $\{hkk\}$ |
| 3. TRISOCTAHEDRON.                 | 24     | $a : a : ma$              | $\{hhl\}$ |
| 4. OCTAHEDRON.                     | 8      | $a : a : a$               | $\{111\}$ |
| Each face parallel to one axis.    |        |                           |           |
| 5. PYRITOHEDRON.                   | 12     | $a : na : \infty a$       | $\{hko\}$ |
| 6. DODECAHEDRON.                   | 12     | $a : a : \infty a$        | $\{110\}$ |
| Each face parallel to two axes.    |        |                           |           |
| 7. CUBE.                           | 6      | $a : \infty a : \infty a$ | $\{100\}$ |

## Description of the Type Forms.

1. DIPLOID. —  $a : na : ma$ ;  $\{hkl\}$ .

Twenty-four faces each cutting the three axes in three different, but simply proportionate, distances. In the ideal form the faces are trapeziums. Fig. 180 shows a positive form.

FIG. 180.

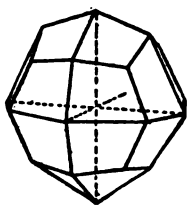
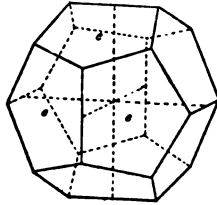


FIG. 181.



2. TRAPEZOHEDRON, Fig. 141.
3. TRISOCTAHEDRON, Fig. 142.
4. THE OCTAHEDRON, Fig. 143.

5. PYRITOHEDRON. —  $a : na : \infty a$ ;  $\{hko\}$ .

Twelve faces, Fig. 181, each parallel to one axis and cutting the other two unequally in distances bearing a simple ratio to each other. In the ideal forms the faces are pentagons.

## 6. THE DODECAHEDRON, Fig. 145.

## 7. THE CUBE, Fig. 146.

**Combinations in the Class of the Diploid.**

FIG. 182.

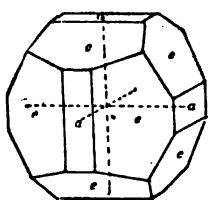


FIG. 183.

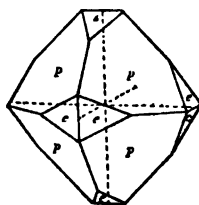


FIG. 184.

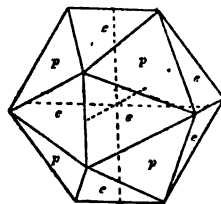


Fig. 182 shows the pyritohedron  $e = (a : 2a : \infty a)$ ;  $\{210\}$ ; with the cube  $a$ . Figs. 183 and 184 show the same form with the octahedron  $p$ .

FIG. 185.

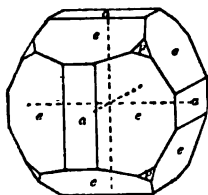


FIG. 186.

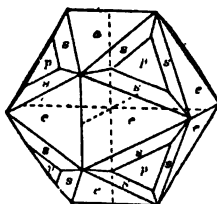


FIG. 187.

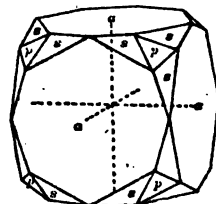


Fig. 185 shows the three forms combined. Fig. 186 shows the same pyritohedron  $e$  and octahedron  $p$  combined with the diploid  $s = (a : \frac{3}{2}a : 3a)$ ;  $\{321\}$ ; and Fig. 187 shows this diploid with the cube and octahedron.

**OTHER CLASSES IN THE ISOMETRIC SYSTEM.**

28. CLASS OF THE TETARTOID. — Three axes of two-fold symmetry at  $90^\circ$  to cube faces and four of three-fold through opposite corners of the cube. Example — Ullmannite.

29. CLASS OF THE GYROID. — Three axes of four-fold symmetry, at  $90^\circ$  to cube faces, four of three-fold through opposite corners of cube, six of two-fold through diagonally opposite edges. Examples — Sylvite, sal-ammoniac.

IMPORTANT SUPPLEMENT ANGLES BETWEEN ADJACENT FACES IN  
ISOMETRIC CRYSTALS.

|                | CUBE 90°                   | OCTAHEDRON 70° 31'                 | DODECAHEDRON 60°     |
|----------------|----------------------------|------------------------------------|----------------------|
|                | CUBE TO OCTAHEDRON 54° 44' | CUBE TO DODECAHEDRON 45°           |                      |
|                |                            | OCTAHEDRON TO DODECAHEDRON 35° 16' |                      |
|                |                            | Polar Edge.                        | Other Edges.         |
| Tetrahexahedra | 320                        | 46° 11'                            | 22° 37'              |
|                | 210                        | 36 52                              | 36 52                |
|                | 310                        | 25 50                              | 53 17                |
| Pyritohedra    | 320                        | 67 22                              | 62 30                |
|                | 210                        | 53 7                               | 66 25                |
|                | 310                        | 36 52                              | 72 32                |
|                |                            | Edge in Axial Plane.               |                      |
| Trapezohedra   | 311                        | 35° 5'                             | 50 28                |
|                | 211                        | 48 11                              | 33 33                |
|                | 322                        | 58 2                               | 19 45                |
|                |                            | Edge in Diagonal.                  | Edge in Axial Plane. |
| Hexoctahedra   | 321                        | 21° 47'                            | 31° 0'               |
|                | 421                        | 17 45                              | 25 12                |
|                |                            |                                    | Other Edges.         |
|                |                            |                                    | 21° 47'              |
|                |                            |                                    | 35 57                |

## CHAPTER VIII.

### THE GROUPING OF CRYSTALS AND THEIR IMPERFECTIONS.

Crystals are more frequently grouped than isolated and with respect to their grouping may be divided into symmetrically grouped or "twin" crystals and unsymmetrically grouped crystals, usually known as crystal aggregates.

#### TWIN CRYSTALS.

Crystals frequently form which consist of two individuals, one of which is reversed with respect to the other. In such crystals re-entrant angles are common.

FIG. 188.

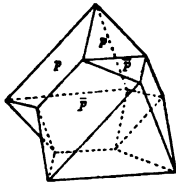
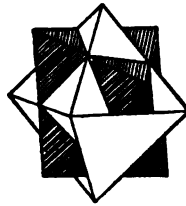


FIG. 189.



Such growths are called twin crystals. If the individuals interpenetrate they constitute a *penetration twin*. If simply in contact along a certain plane they constitute a *contact twin*. Fig. 188 shows a contact twin octahedron very frequent in the spinel group. Fig. 189 shows the corresponding penetration twin.

#### Symmetry of Twin Crystals.

The crystal may be (a) symmetrical only to a line called a "twin axis," always parallel to a possible edge of the crystal but never an axis of two-, four- or six-fold symmetry. Fig. 190 shows pyroxene with the twin axis parallel to a prism edge. Fig. 191 shows the "Iron Cross" of pyrite, a twin pyritehedron with the twin axis a cubic edge. Fig. 192 shows quartz with the twin axis parallel a prism edge; these frequently penetrate and as the positive

rhombohedron of one coincides with the negative of the other, the twin structure is then only recognized by etching.

FIG. 190.

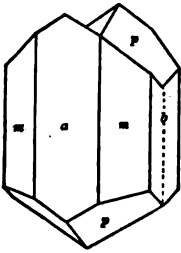


FIG. 191.

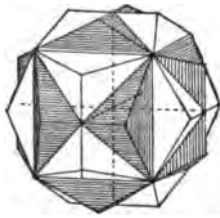
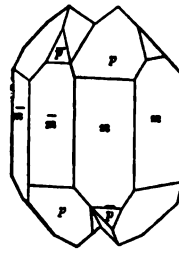


FIG. 192.



(b) Symmetrical to a *twin axis* and also to a "*twin plane*" at right angles to the axis. The plane is always parallel to a possible face of the crystal but never a plane of symmetry for either individual.

Fig. 193 shows an aragonite twin, the twin plane a prism face. Fig. 194 shows a twin cube, the twin plane being an octahedral

FIG. 193.

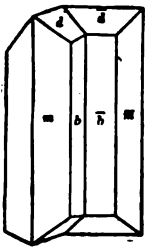


FIG. 194.

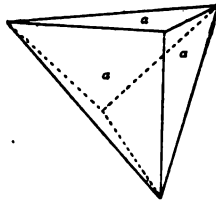
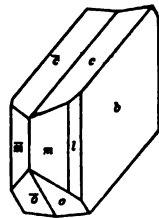


FIG. 195.



face. Fig. 195 shows a twin of albite, the brachy pinacoid being the twin plane.

### Repeated Twinning.

Frequently there is a repetition of the twinning, a third individual occurring reversed upon the second, a fourth upon the third, and so on.

If the successive twin planes are parallel the phenomenon is called "*polysynthetic twinning*," the individuals may be thin lamellae and the re-entrant angles striae. Fig. 196 shows the polysynthetic twinning of albite.

If the successive twin planes are oblique to each other repetition may lead to "*circular forms*" as in orthorhombic marcasite with the prism face the twin plane, Fig. 197, because the prism angle  $74^{\circ} 55'$  is approximately one fifth of  $360^{\circ}$ .

FIG. 196.

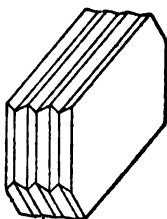


FIG. 197.

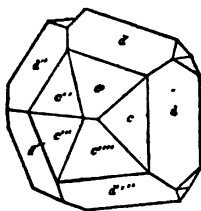
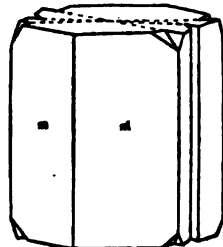


FIG. 198.



Sometimes the "circular form" is *pseudosymmetrical* and approximates a higher class of symmetry; for instance, repetition of Fig. 193 leads to pseudohexagonal forms, Fig. 198, the prism angle being  $63^{\circ} 48'$ .

#### CRYSTAL AGGREGATES.

Crystals of any substance even when not grouped symmetrically may be grouped with a degree of regularity characteristic of that particular occurrence of the substance and sometimes characteristic of many occurrences.

#### The Individual Crystals of an Aggregate.

Unless formed while floating, like snow crystals in air, or gypsum crystals in clay, or leucite in a molten magma, the individual crystal will not be completely bounded by plane faces. If formed in a cavity attached to and projecting from the rock the opposite ends will be plane faced and so much of the rest as is free. As compactness increases the plane faces diminish in number and may entirely disappear, although the individual may still be evident. Finally, the individuals may be microscopic and the mass dense.

#### Terms Dependent on the Shape and Grouping of the Individual Crystals of an Aggregate.

Whether showing plane faces or not the individuals may be distinguished *as to their shape* by such terms as:

*Columnar*—when the individual crystals are relatively long in one direction, Fig. 199.

*Bladed*—a variety of columnar in which the columns are flattened like a knife blade.

*Fibrous*—a variety of columnar in which the columns are slender threads or filaments, Fig. 200.

*Lamellar*—when the individual crystals appear as layers or plates, either straight or curved.

*Foliated*—a variety of lamellar in which the plates separate easily.

FIG. 199.



Columnar Beryl.

FIG. 200.



Fibrous Serpentine.

*Micaceous*—a variety of lamellar in which the leaves can be obtained extremely thin.

*Granular*—when the individual crystals are angular grains, either coarse or fine.

*Impalpable or dense*—a variety of granular in which the grains are invisible to the naked eye.

With respect to the grouping, the individual crystals may be:

*Parallel*—in crystals with plane faces this may extend to all corresponding faces and edges, Fig. 201, and may be recognized by the simultaneous reflection of light from parallel faces, or it may be partial with respect to an edge or a face.



In crystals lacking plane faces there result parallel fibers, blades, columns, lamellae, etc.

FIG. 201.



Parallel Copper Crystals.

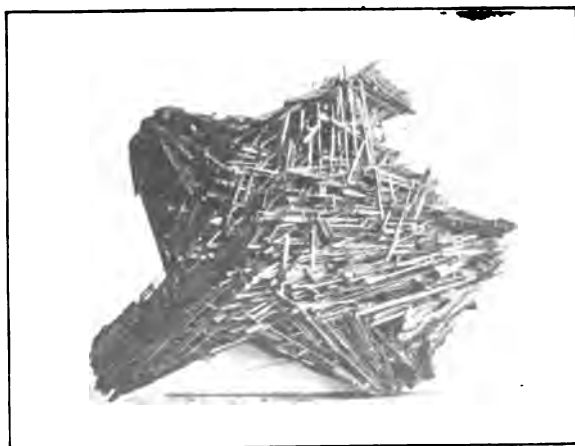
*Radiating*—diverging from a common center.

*Reticulated*—crossing like the meshes of a net, Fig. 202.

*Rosetted*—overlapping like the petals of a rose.

*Drusy*—minute crystals resting close together on a common underlayer, giving a rough sand-paper like surface.

FIG. 202.



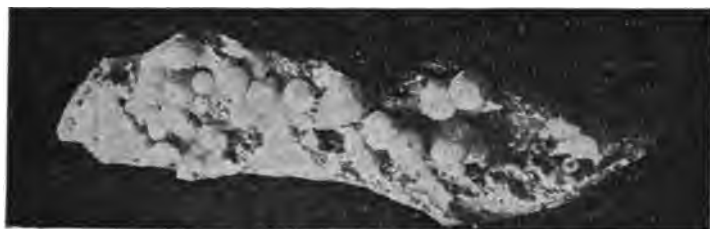
Reticulated Stibnite.

FIG. 203.



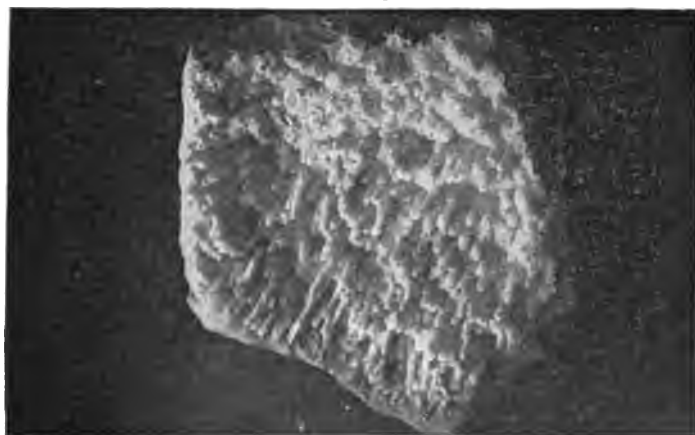
**Reniform Hematite.**

FIG. 204.



**Botryoidal Prehnite.**

FIG. 205.



**Stalactitic Gibbsite.**

**Terms Describing the External Shape of Aggregates.**

Many terms are used. The more important of these are:

*Reniform*—with the shape of a kidney, Fig. 203.

*Botryoidal*—resembling a bunch of grapes, Fig. 204.

*Mammillary*—flatter but rounded shapes.

*Pisolitic*—small rounded particles the size of a pea.

*Oölitic*—similar but smaller like fish roe.

*Nodular*—occurring in separate rounded lumps or nodules.

*Stalactitic*—in hanging cones like icicles, Fig. 205, 206.

FIG. 206.



Stalactite of Limonite.

*Cockscomb*—the free ends of radiating crystals forming a ridge.

*Plumose*—like a feather.

*Sheaf-like*—resembling a sheaf of wheat.

*Arborescent or Dendritic*—branching like a tree, Fig. 207.

*Mossy*—similar to dendritic but a more minute structure.

*Coralloidal*—like coral in form.

*Amygdaloidal*—almond-shaped.

*Wire-like*—as in silver.

*Geode*—a hollow nodule lined with crystals.

**TERMS OF GROWTH AND "HABIT."**

Dependent upon the conditions of growth crystals may be "Embedded" in a groundmass, Fig. 208, or "Attached" by one end to the rock and extending into free space. The former has a chance for complete plane faced boundaries, the latter necessarily lacks some of the faces.

FIG. 207.



Arborescent Copper.

**Habit.**

The term habit is used to express the usual or prevailing shape of the crystals of a substance. The habit under one set of conditions at formation is fairly constant, both as to occurring forms and their relative development. The habit for another set of

FIG. 208.



Embedded Pyrite in Schist.

conditions (another locality) may involve just the same forms with a different relative development or the forms themselves may be different.

The principal terms of habit are:

### Prismatic Habit.

Notably elongated in one direction, which is liable to be the direction of the optic axis or of an axis of symmetry or of the intersection of cleavages.

### Tabular Habit.

Notably extended parallel some prominent plane, either a cleavage or, if uniaxial, at right angles to the optic axis.

Other terms, as cubic, octahedral, pyramidal, with the prefix habit, imply that the usually dominant form is the cube, octahedron and pyramid respectively.

Figs. 209 and 210 represent quartz crystals composed of the same common forms  $m \{10\bar{1}0\}$ ,  $p \{10\bar{1}1\}$ ,  $\bar{p} \{01\bar{1}1\}$ , in Fig. 209 the

FIG. 209.

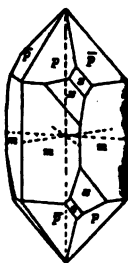


FIG. 210.

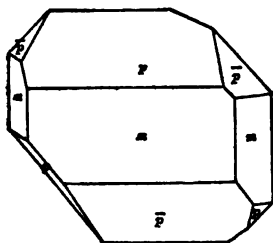
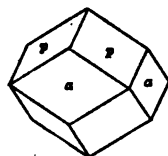


FIG. 211.



equivalent faces are equal sized, in Fig. 210 they are not, but in each case equivalent faces are directions of equivalent structure, and the crystal symmetry and interfacial angles are the same in both. Sometimes the forms appear to be of higher or lower symmetry than that proper to the substance, for instance, the not unusual combination in zircon of the forms  $p \{111\}$  and  $a = \{100\}$  may develop as in Fig. 211 suggesting the isometric dodecahedron, although the supplement angles  $p : p$  and  $p : a$  instead of being  $60^\circ$  are respectively  $56^\circ 40'$  and  $61^\circ 40'$ . Conversely, the isometric dodecahedron sometimes develops so as to closely imitate the prism  $\{100\}$  and pyramid  $\{111\}$  of zircon.

**Skeleton Crystals.**

If the material comes faster to the edges than elsewhere the faces become relatively depressed or hopper-shaped as in cuprite, Fig. 212, or if the dominant accretion is at the solid angles composite patterns like those of snow crystals or gold may result.

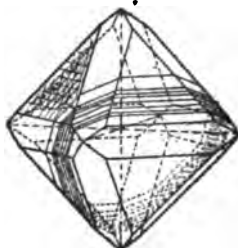
FIG. 212.



FIG. 213.



FIG. 214.



Sometimes the faces build up most quickly, leaving the edges relatively depressed, as in quartz.

(d) *Microlites*.<sup>\*</sup>—Microscopic, not easily identified rods and needles frequently rounded or frayed at the ends, Fig. 213.

**IRREGULARITIES OF FACES OF CRYSTALS.**

The perfectly smooth and plane crystal is difficult to find, except in very minute crystals.

**Striated Faces.**

Crystal faces are frequently marked by parallel lines or fine "grooves" called "striations" each of which is bounded by two definite planes. That is, they are parallel to edges. Usually they line a face in one direction only, sometimes in two, or more often three, and frequently not intersecting but branching feather-like from a common line.

They may occur on simple crystals as in chabazite, but often are due to repeated or polysynthetic twinning, Fig. 196. If the individuals are thin the reëntrant angles become grooves or striations. Fig. 215 shows twinning striations on a magnetite crystal from Port Henry, N. Y.\*

At other times striations result from an oscillation or contest between two crystal forms. This is true of the striations on the

\* Crystallites, a name applied to minute forms not crystalline in shape, are now held to be molecular mixtures of different substances.

prism faces of quartz, which are due to an alternate formation of prism and rhombohedron; or the striations on pyrite due to an oscillation between the cube and the pyritohedron, Fig. 215.

FIG. 215.



Striated Pyrite, Aspen, Colo. After S. Smillie.

#### **False or Apparent Faces.**

Oscillatory stria may be so frequent as to give rise to an apparent plane made up of these edges. It will not reflect a signal. Apparent faces may also result from the contact of the crystal during growth with an already formed crystal.

#### **Vicinal Faces.**

Prominent faces with simple indices are sometimes replaced wholly or in part by flattened pyramids, the faces of which are in definite zones but with complicated indices. Concentration currents which are too feeble to completely cover the larger faces are a possible explanation. Like etch figures, they usually belong to forms which prove the true symmetry of the crystal.

#### **Roughened or Coated Faces.**

The faces of crystals may be coated with minute crystals of the same or some other substance. Sometimes only particular faces are so covered. Secondary growths and natural etchings may also roughen faces.

#### **Curved Faces.**

Curved faces are not frequent and are nearly always convex. They may be due to strains after formation which exceeded the elastic limit as in stibnite, gypsum, galenite.

Sometimes the edges appear to have been melted as in many apatites, aügites and hornblendes.

*Apparently Curved Faces.*—A rounded effect may be produced by many true faces in one zone, as in beryl, or by a series of vicinal faces each nearly parallel to the preceding as in diamond.

Crystals also appear curved because composed of individual smaller crystals only approximately parallel as in dolomite or siderite.

#### INTERNAL PECULIARITIES.

##### Zonal Structures.

The deposition of layer after layer on the growing crystal is not usually observable unless there has been an intermittent growth or some change in the composition of the material deposited. Intermittent growth permits between layers the depositing of dust or fine lamellæ of a foreign substance and this may be repeated several times. Such may be the explanation of "phantoms" in which an earlier stage of growth is delicately outlined as in quartz, gypsum and fluorite.

There may also result parallel planes of easy separation, *e. g.*, capped quartz.

Often the inner kernel is like the outer hull in shape but it may be a different form, *e. g.*, calcite kernel ( $01\bar{1}2$ ) hull ( $10\bar{1}1$ ).

Change of composition tends to layers of different colors or transparency, *any* of which reveal the zonal structure. California tourmalines are good examples.

The partial decomposition of a crystal may also develop or make visible the zonal structure.

##### Hour-Glass Structure.

This is essentially a variety of zonal structure with the revealing of the "growth pyramids" upon each face of the nucleus, the total shape suggesting an hour glass as in many aügites.

##### Inclusions.

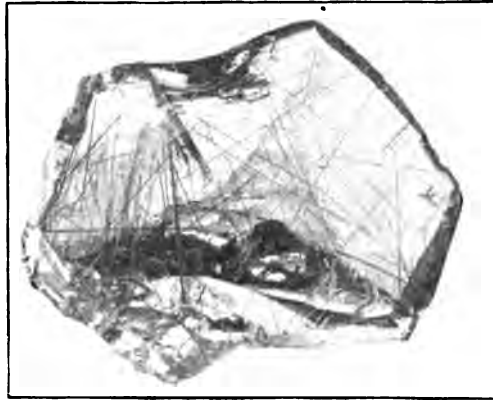
Foreign substances shut in a crystal during rapid solidification may be solid, liquid or gaseous. Solid inclusions may be separations from enclosed magma or aqueous solution, or due to alteration or be mechanically retained during crystallization of an impure mixture. Such solids are:



(a) Glass, from enclosed magma.

(b) Crystals from magma or solutions, often microlites or long prismatic like rutile (Fig. 216), actinolite or tourmaline in quartz, or plate-like, as in the minute scales of iron oxide in hypersthene, sunstone or carnallite.

FIG. 216.



Rutile in Quartz, N. C.

(c) Sand or other associated material as in the crystals of calcite called Fontainebleau limestone, which contains sometimes as much as sixty percent of silica.

These solids may show no evidence of arrangement or may be definitely arranged as in the case of the magnetite in mica or the carbonaceous material in chialtolite as shown in successive sections of a crystal in Fig. 217.

FIG. 217.



#### **Liquid Inclusions.**

Chalcedony, quartz, topaz, halite, and other species frequently contain microscopic cavities partially filled with water, brine, liquid carbonic acid and other liquids.

#### **Gaseous Inclusions.**

Occur in round and simple cavities or negative crystals.\* Usually the gas is under high pressure and may be water vapor, hydrocarbons such as marsh gas, nitrogen and carbonic oxide.

**INTERGROWTHS AND PARALLEL GROWTHS OF TWO DIFFERENT MINERALS.**

Crystals of two minerals forming at the same time may:

(a) Mutually penetrate each other, for example, quartz and orthoclase in graphic granite.

(b) Arrange themselves with a certain face or edge of one parallel to a corresponding part of another; for example, staurolite and cyanite with brachy pinacoids parallel.

(c) The larger mass may orient the smaller; for example, prisms of rutile on hematite with the prism edge of rutile perpendicular to an edge of hematite and the prism face of rutile in contact with basal plane of hematite.

**Form of Amorphous Minerals (Colloids and Glasses).**

Natural minerals of colloidal origin (see p. 235) are frequently reniform (kidney-shaped), botryoidal (grape-shaped), stalactitic, and in other rounded shapes. With lack of space they may be dendritic. Often cracked as result of drying.

Natural glasses often show fluidal texture.

\* Supposed to form when the shut in liquid contains more molecules of the same material as the host. Their separation against the walls of cavities give the faces

## CHAPTER IX.

### THE DETERMINATION OF THE GEOMETRICAL CONSTANTS OF A CRYSTAL.

This chapter outlines\* a simple method in crystal examination with a one circle goniometer, stereographic projection and graphical or zonal solutions, under the principal divisions of:

- I. Measurement of the Interfacial Angles.
  - II. Stereographic Projection.
  - III. Determination of Symmetry and Selection of Elemental Faces.
  - IV. Zonal and Graphic Determination of Indices.
  - V. Calculation of Axial Elements.
- To this is added:
- VI. Crystal Drawing.

#### I. MEASUREMENT OF INTERFACIAL ANGLES.

The angles between smooth bright faces can be measured to half minutes or even closer on a one circle reflecting goniometer as follows:

The available crystals are carefully examined. Good crystals with bright smooth faces are more apt to be found among little crystals than large ones. During examination they are handled by either a pencil of wax or by the forceps, never by the fingers.

Each selected crystal is studied with a hand-glass and a sketch is made, usually a horizontal projection of the crystal with some selected zone vertical such as is described p. 6.

#### The Goniometer.

Among "one-circle" goniometers one of the best and simplest is the Fuess† (4, A) shown\* in Fig. 218.

\* For a more complete description of the same course see A. J. Moses, in the *School of Mines Quarterly*, Vol. XXVII, July, 1906, p. 432.

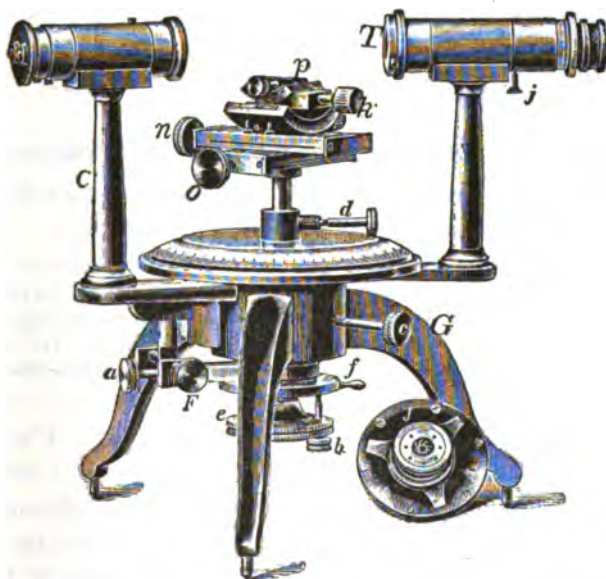
† R. Fuess, Steglitz, near Berlin, marks 260, or about 65 dollars.

The axes of the two telescopes, *C* and *T*, are in the same horizontal plane and intersect in the axis of rotation.

Before the objective of the observation telescope *T* is an extra lens which brings the crystal into focus. When it is raised the telescope is focused through the collimator, upon the light.

The crystal carrier, shown between the telescopes, includes three motions in straight lines at right angles to each other (by the axis and the slides *n* and *O*) and two tipping motions on circular arcs at right angles. The crystal is attached by wax at *p* and the desired edge\* made coincident with the axis of rotation.

FIG. 218.



### The Measuring.

The telescope *T* is set at 100 to 120 degrees to the collimator *C*, the graduated circle and crystal are turned together by the wheel *f*, Fig. 218, until the reflected signal, Fig. 219, is seen through the telescope, the screw *a* is tightened, the fine adjustment made by the tangent screw *F*, and the vernier read.

The screw *a* is again loosened and the rotation continued until the signal, Fig. 219, is received from a second face; this is centered

\* With small crystals all the angles of a zone may be measured with one adjustment.

by  $F$  and  $a$  and recorded as before. *The difference between the two readings is the supplement angle\* between the faces.*

The best order of measurement, methods of recording, averaging of corresponding angles, adjustments of apparatus, and other details are given in the more complete descriptions.

FIG. 219.

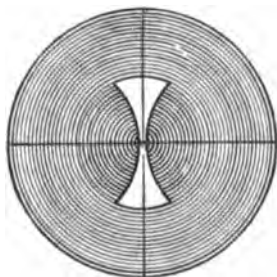
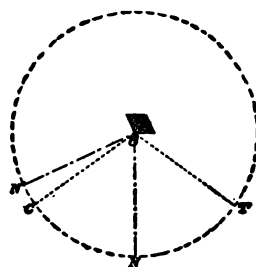


FIG. 220.



## II. THE STEREOGRAPHIC PROJECTION† OR STEREOGRAM.

That is the projection of an imaginary surrounding sphere upon its equatorial plane by lines drawn to its south pole.

The crystal is assumed to be surrounded by a sphere, the centers of the sphere and the crystal coinciding, and radii to be drawn from the center *perpendicular to each face* of the crystal. From the point  $P$  where any such radius cuts the surface of the sphere (called the pole of the corresponding face) a line, Fig. 221, is supposed to be drawn to the south pole  $S$ , and the point  $P'$  where this line pierces the equatorial plane is the stereographic projection of the face.

The method of projection varies with the face. A very brief outline would be as follows:

Select the plane of projection, usually perpendicular to a zone of prominent or numerous faces, or to an apparent axis. Draw a circle of any convenient diameter, and let the point  $B$ , Fig. 222, be taken as the pole of a chosen vertical face.

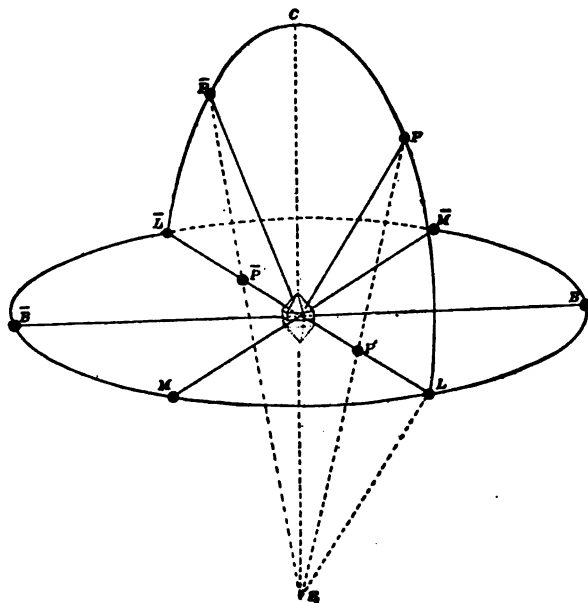
\* Because under the conditions stated both telescopes are fixed in directions, say  $OC$  and  $TO$ , Fig. 220.

If  $ON$  and  $ON'$  are the normals to the two crystal faces  $NON'$  will be the supplement angle between the faces. The two reflections will occur when  $ON$  and  $ON'$  respectively bisect  $COT$ . The *difference* in rotation to these positions being  $NON'$ .

† By this method vertical zone-circles project as diameters, oblique zone circles as circles, each passing through both ends of a diameter and face-poles project as points. Small circles also project as circles. The entire projection is called a "stereogram."

The zonal relations and the spherical triangles are therefore all represented; and can be graphically solved or calculated.

FIG. 221.



Perspective of a Stereographic Projection.

### Projecting the Vertical Faces.

Measure the supplement angles between this face and any other vertical face  $L$  and lay off the corresponding arc  $BL$  upon the circumference, thus determining the projection of  $L$ .

### Projecting Oblique Faces on Known Diameters.

If any oblique face lies in a zone with a horizontal and a vertical face its projection is on the diameter through the vertical face.

If the face makes equal angles with any two vertical faces, its projection is on the diameter midway between the diameters through the projections of the two vertical faces.

In either case the distance of the desired projection from the center may be found by laying off  $CD$ , Fig. 222, equal to the angle with the horizontal face (or  $BD$  equal the angle with the vertical face of the same zone) and drawing  $DS$ . Then is  $OR$  the desired distance,\* and is laid off upon the proper diameter (in this case on  $BB'$ ).

\* The distance may be laid off by a protractor, devised by Professor Penfield, in which the values of the stereographically projected degrees have been determined for a circle of convenient size.



horizontal face. The projection then involves the drawing of projected small vertical and horizontal circles. Failing these oblique small circles must be drawn.\*

### III. DETERMINATION OF THE SYMMETRY AND THE ELEMENTAL FACES.

#### Determining the Symmetry.†

This can usually be determined by two tests directly from the stereographic projection.

1. If by revolving a tracing of the projection on the projection itself about the coincident centers, all the poles of the tracing *coincide with* those of the projection *more than once* in a complete revolution, then an axis of two-fold, three-fold, four-fold or six-fold symmetry exists in the crystal perpendicular to the plane of projection.

2. If by folding the paper tracing on *any* diameter, *all* the poles of the one half cover those of the other, then this diameter is the trace of a plane of symmetry perpendicular to the plane of projection.

The following table will identify the "system" unless a very unimportant zone has been chosen as the vertical zone.

| Symmetry<br>of Center. | Diameters<br>of Symmetry. | System.                   |
|------------------------|---------------------------|---------------------------|
| Six-fold               | Six or none               | Hexagonal                 |
| Four-fold              | Four, two or more         | Isometric or Tetragonal   |
| Three-fold             | Three or none             | Hexagonal or Isometric    |
| Two-fold               | Two or none               | Isometric or Orthorhombic |
| Two-fold               | None                      | Monoclinic                |
| None                   | One                       | Monoclinic                |
| None                   | None                      | Triclinic                 |

The isometric crystal will always yield the same projection for some other position, also in projections of isometric crystals there are three points  $90^\circ$  apart which are surrounded by the same grouping of planes. In tetragonal projections there are two such points.

\* Explained in detail in *School of Mines Quarterly*, Vol. 27, p. 441.

† This is tentative, other crystals of the same substance may reveal faces which lower the symmetry. Indeed the true symmetry of a crystal is known only when all the characters have been considered. Structurally equivalent directions not only imply similar groupings of bounding faces but physical identity in all respects.



### Choosing Elementary Faces.

The three axial planes (100), (010) and (001) and the "parametral" plane (111) are essential to the determination of axes, parameters and indices.

The axial planes are each parallel to two crystal axes (or conversely the crystal axes are parallel to their intersection), their choice therefore is dependent on the symmetry.

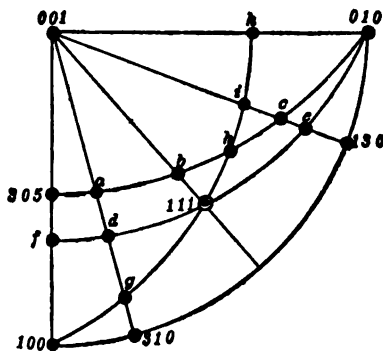
If any ( $hkl$ ) face occurs it may be chosen as (111) or lacking such a face any two of ( $okl$ ), ( $hol$ ), ( $hko$ ) may be chosen as (011), (101) or (110) and from these the position of (111) be found.

### IV. ZONAL AND GRAPHIC DETERMINATION OF INDICES.

#### Zonal "Indices."

All edges of a zone are parallel. Their common direction is called the zone axis. There must be a radius in a spherical projection parallel to each zone axis, and this radius is known if the indices of the point at which it cuts the sphere are known. These three numbers are called zone indices and may be derived from the indices of any two faces of the zone\* by cross multiplication and subtraction of the twice written indices (striking off end terms and reading down alternately from left to right and from right to left).

FIG. 223.



For instance, in Fig. 223, a zone with  $i = (133)$  and  $g = (311)$ , the values of the zone indices  $[uvw]$  are obtained as follows:

$$\begin{array}{r|rrrr|l} 1 & 3 & 3 & 1 & 3 & 3 \\ & \times & \times & \times & & \\ 3 & 1 & 1 & 3 & 1 & 1 \end{array} \quad \begin{array}{l} u = 3 - 3 = 0 \\ v = 9 - 1 = 8 \text{ or } [uvw] = [088] = [011] \\ w = 1 - 9 = 8 \end{array}$$

#### Face in Two Zones.

The indices of a face in two zones result from a similar cross multiplication of the two sets of zone indices. For instance, if a face  $h$ , Fig. 223, lie in the zone of  $i = (133)$  and  $g = (311)$  for

\* Miller's Treatise on Crystallography, 1839, pp. 7, 8 and 10.

which the zone indices are  $[01\bar{1}]$  and also in the zone of  $b = (335)$  and  $c = (395)$  for which similarly the zone indices are  $[\bar{5}03]$ , the values of  $(hkl)$  the indices of the face  $h$  are  $(355)$  for

$$\begin{array}{c|ccc|c} 0 & 1 & \bar{1} & 0 & 1 & \bar{1} & h = 3 - 0 \\ & \times & \times & \times & & & k = 5 - 0 \text{ or } (hkl) = (355) \\ \bar{5} & 0 & 3 & \bar{5} & 0 & 3 & l = 0 + 5 \end{array}$$

Various special and more rapid methods of utilizing zone indices exist, for instance, *In any zone passing through two of (001), (010), (100). Every face in the zone will have that index zero which is zero in both.* That is:

For zone (001), (010) the type symbol is  $(okl)$ ,  
 " " (001), (100) " " " "  $(hol)$ ,  
 " " (010), (100) " " " "  $(hko)$ .

Even more useful is the determination of symbols by zones through one of (001), (010) or (100).

*The ratio of the two indices, which are zero for (001), (010), or (100), is constant for all faces of the zone.* Hence:

Zones through (001)  $h/k$  constant,  
 " " (010)  $h/l$  " ,  
 " " (100)  $k/l$  " .

If then an unknown face lie at the intersection of two such zones and the indices of one face in each zone are known the indices of the unknown face become known.

For instance, Fig. 223, the same unknown face  $h$  lies in a zone with (010) and (305) and also in a zone with (100) and (111).

To substitute in  $hkl$  we have therefore

From first zone, 3, -, 5.

From second zone, -, 1, 1.

Remembering these are ratios and combining by inspection, the indices of the face  $h$  must be  $(355)$ . Similarly the indices of the face  $b$  must be  $(335)$  and of  $k$  must be  $(011)$  and  $e$   $(131)$ , etc.

### Graphical Determinations of Indices.

It will usually happen that only the indices of a few faces can be obtained *directly* by zonal equations, certain factors being



section of the corresponding radius with the tangent at  $B$ . Take  $RT$  parallel  $CB$  as unity. Similarly measure the angle  $001 \wedge okl$ , lay this off from  $A'$  as  $A'D$  and find the intersection  $T'$ , Fig. 225, of the corresponding radius with  $RT$ , then

$$RT' = \frac{k}{l} = \frac{1}{2} \text{ in Fig. 225.}$$

The same angles are used in Fig. 225 as in Fig. 224; hence combining by inspection with  $\frac{3}{2} = \frac{h}{k}$  we have

$$\begin{array}{c} 3, 2, -, \\ -, 1, 2, \end{array}$$

that is 324 satisfies both, hence  $P = (hkl) = (324)$ .

#### V. THE CALCULATION OF AXIAL ELEMENTS.

Simple formulæ in terms of the indices and interfacial angles are most used. For the fairest average every available measured angle should have due weight. Considering the systems in order:

##### The Isometric System.

In this system the parameters are equal and the angles between the axes are right angles.

##### The Tetragonal System.

Taking the parameter  $a = 1$  the only axial element is  $c$ .

The formulæ of the orthorhombic apply if  $a$  is made equal unity ( $a = 1$ ).

##### The Orthorhombic System.

Taking the parameter  $b = 1$  the axial elements are  $a$  and  $c$ . The simplest formulæ are:

$$a = \frac{h}{k} \tan (100) \wedge (hko); \quad c = \frac{l}{k} \tan (001) \wedge (okl).$$

- Similar but somewhat more complex formulæ exist for the  $(hkl)$  angles.

##### The Hexagonal System.

Taking the parameter  $a = 1$  the only axial element is  $c$ .

The simplest formulæ for this are

$$\begin{aligned} c' &= \frac{l}{h} \cos 30^\circ \tan (0001) \wedge (h\bar{o}hl) \\ &= \frac{l}{2h} \tan (0001) \wedge (hh\bar{2}hl). \end{aligned}$$

### The Monoclinic System.

Taking the parameter  $\bar{b}$  as unity the axial elements are the values of  $\bar{a}$  and  $\bar{c}$  and of the acute angle  $\beta$  between the vertical and clino axes.

$$\begin{aligned} \beta &= (100) \wedge (001), \\ \cos \beta &= \frac{\cos (001) \wedge (hko)}{\cos (010) \wedge (hko)}. \end{aligned}$$

The simplest formulæ for  $\bar{a}$  and  $\bar{c}$  are

$$\begin{aligned} \bar{a} &= \frac{h}{k} \frac{\cot (010) \wedge (hko)}{\sin \beta}, \\ \bar{c} &= \frac{l}{k} \frac{\tan (001) \wedge (okl)}{\sin \beta}. \end{aligned}$$

### The Triclinic System.

The axial elements are the parameters  $\bar{a}$ ,  $\bar{b}$  and  $\bar{c}$ , in which  $\bar{b}$  is taken as unity and the angles between the axes  $\alpha = \bar{b} \wedge \bar{c}$ ,  $\beta = \bar{a} \wedge \bar{c}$  and  $\gamma = \bar{b} \wedge \bar{a}$ .

The formulæ are much more complex; for instance the simplest is

$$\cot \frac{\alpha}{2} = \sqrt{\frac{\sin (S - AC) \sin (S - AB)}{\sin S \sin (S - BC)}},$$

in which

$$A = (100), C = (001), B = 010 \text{ and } S = \frac{1}{2}(AB + BC + AC).$$

## VI. CRYSTAL DRAWING.

Clinographic and orthographic projections of crystals are much used in illustration.

### Clinographic Projections.

In clinographic drawings the crystal is projected upon a vertical plane by parallel rays oblique to the plane of projection. The eye is assumed at an infinite distance a little to the right and above the center of the crystal.

The figures obtained in this way have an appearance of solidity, all parallel edges are parallel and all points in a given line remain the same *proportionate* distances apart.

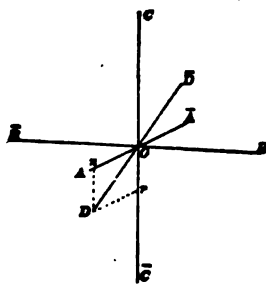
The drawing consists chiefly of two stages, first finding the "axial cross" of the crystal, that is the true projection of the crystal axes cut off at the parameter lengths; second, finding the direction of the projection of any edges from the indices of the intersecting planes.

### Construction of "Axial Cross."

All axial crosses are derived from the projection of three equal lines at right angles, that is, from the isometric axial cross\* for constructing which formulæ exist dependent on the direction of the line of sight.

For other systems the necessary changes† are made in the *directions* of these isometric axes and then each is changed in length to fit the parameters of the species.

FIG. 226.



Thus in a monoclinic species the angle between the clino and vertical axes being known the projection of the front to back isometric axis is replaced by the projection of a line *equal in length to an isometric axis* but in the *direction‡* of the desired clino axis.

These three lines, Fig. 226, are then lengthened or shortened in the proportions given by the parameters of the species. If  $a : b : c = 0.73 : 1 : 1.23$ , the left to right axis is not changed, the vertical is made 1.23 times its isometric length and the front to back axis 0.73 its isometric length  $DD$ .

\* For the drawings of this book the projected isometric "axial cross" consists of three lines.  $OA : OB : OC = 37 : 100 : 104$ , in lengths intersecting at a common center and with  $BOC = 93^\circ 8'$ ,  $AOC = 116^\circ 17'$ . See Fig. 226.

† See A. J. Moses, *Characters of Crystals*, pp. 79-84.

‡ To obtain this *direction* in perspective proceed as follows: Upon the isometric "cross" lay off  $Or = OC \cos \beta$  and  $On = OA \sin \beta$ , Fig. 226. Complete the parallelogram  $OrDn$ ; then is  $DD$  the projection of a line equal in length to an isometric axis but in the *direction* of the desired clino axis.

**Determination of the Direction of Edges.\***

The unit form is obtained by joining the extremities of the axial cross by straight lines, and other simple forms are easily drawn by methods which suggest themselves.

The projection of the edge between any two planes may be derived from the reciprocals of the Miller indices or the Weiss coefficients as follows:

For instance in Fig. 227 let  $OA$ ,  $OB$ ,  $OC$  be one half of any projected axial cross and the problem be to find the projection of the edge between two planes for which the symbols are:

$$\text{The dome} \quad \infty a : \bar{b} : 4c \text{ or } (041),$$

$$\text{The prism} \quad a : \bar{b} : \infty c \text{ or } (110).$$

The respective Weiss coefficients or reciprocal Miller indices are

$$\infty : 1 : 4, \text{ and } 1 : 1 : \infty.$$

Dividing each by the third term, which is equivalent to moving each face parallel to itself until it cuts  $c$  at its parametral value  $OC$ ,

$$\text{The dome} \quad \infty : \frac{1}{4} : 1; \text{ The prism} \quad 0 : 0 : 1.$$

The traces of these planes on  $AOB$  are respectively  $Y\bar{Y}$  and  $OS$ . These traces intersect at  $S$ .

The two planes have therefore one point in common at  $S$  and one at  $C$ , hence the desired projected edge\* is parallel  $SC$ .

All other intersections may be obtained in the same manner on the axial cross.

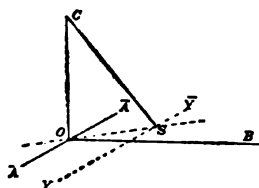
**Construction of the Figure.**

Generally the principal forms are drawn first and the minor modifying planes later, either in ideal symmetry or so as to indicate the relative development of faces and forms.

A second axial cross may be drawn parallel to that used in determining the edge directions and these may be transferred by triangles.

\* Prismatic traces, such as  $OS$  for  $(110)$ , involve considering the trace of the corresponding pyramid, that is,  $0 : 0 : 1$  means a line  $OS$  through the centre *parallel* to  $AB$  (not drawn), the trace of the pyramid  $(111)$ .

FIG. 227.



**Orthographic Projections.** (See Figs. 6 to 10.)

The projection upon a plane by lines perpendicular to that plane. Usually a prominent zone is placed perpendicular to the plane of projection and its faces appear as lines inclined to each other at their true values.

**The Projection of Oblique Edges** is very much as in clinographic projection. If, as is usual, the plane of projection is the plane of two crystal axes then the projection of any oblique edge is obtained by drawing the axes, and finding the traces of each plane by laying off on these axes the proper intercepts.\* The intersection of any two traces is a point of the edge, the intersection of the two axes is another.

If a stereographic projection upon the same plane has been made *the tangent to the outer circle at the point where it is cut by the zone of the two planes is the direction of their edge.*

\* As in clinographic projection, the intercepts are reduced so that the third term is unity.



## CHAPTER X.

### CRYSTALLO-OPTICS.

Light, the agent which by its action on the retina produces the sensation of vision, is transmitted in any homogeneous medium in straight lines which may be called light rays.

There is a vibration, or a waxing and waning of force, at right angles to the direction of transmission which may be designated in direction and intensity by a straight line at right angles to the direction of advance and may for convenience be called a vibration.

In common light these "vibrations" may be thought of as constantly altering in direction though always in the same plane and changing so rapidly that the effect during the period of a distinct impression upon the retina is an average of many.

It is possible, however, by certain methods later to be explained to reduce these vibrations of many orientations to one direction, that is, to "polarize" common light.

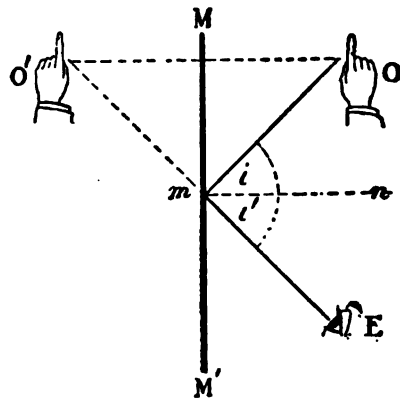
#### Reflection.

Rays of light falling on a polished surface are reflected and follow two laws.

1. The angle of incidence is equal to the angle of reflection.
2. Both rays are in the same plane perpendicular to the reflecting surface.

Let  $MM'$ , Fig. 228, be a section of a mirror. The hand at  $O$  appears to be seen at  $O'$  by the eye at  $E$ , the line  $OO'$  being perpendicular to the mirror and bisected by it. The angles  $i$  and  $i'$  are equal.

FIG. 228.



**Refraction.**

Rays of light in passing *obliquely* from one medium to another in which the velocity of transmission is different are bent or refracted. If the velocity is lessened the bending is *towards* the perpendicular to the surface of contact, if the velocity is increased the bending is *away* from the perpendicular. Thus in Fig. 229 let  $AB$  represent the surface of contact and let the light velocity be slower in the lower medium. Any ray of light  $CO$  on entering this medium is bent *towards* the perpendicular  $ON$  and follows a path such as  $OD$ , similarly  $C'O$  follows  $OD'$ .

Conversely if the light travels in the opposite direction, on reaching  $AB$  the rays would be bent *from* the perpendicular  $ON$ .

**Index of Refraction.**

It has been proved that whatever the angle of incidence, the ratio of the sines of the angles of incidence and the angle of refraction is constant for the same two media and equal to the ratio of the velocities of the incident and the refracted ray. That is,

$$n = \frac{\sin i}{\sin r} = \frac{V_1}{V_2}.$$

Thus in Fig. 230 the ratio  $\frac{\sin i}{\sin r}$  or  $\frac{ab}{cd}$  is equal to the ratio  $\frac{\sin i'}{\sin r'}$  or  $\frac{a'b'}{c'd'}$ . This constant ratio for any two media is called the index of refraction of the second medium with respect to the first. Unless otherwise specified a stated index of refraction assumes the first medium to be air.\*

There is no refraction with normal incidence. With a plane-parallel plate the ray emerging at the second surface is parallel to the ray entering at the first surface.

If the indices of refraction of two media with respect to air are known the *direction* of any ray after bending may be found by drawing concentric circles as in Fig. 230 with radii corresponding to these indices. In the circle corresponding to the first medium a diameter is drawn parallel to the incident ray. From its end  $T$  (or  $T'$ ), Fig. 230, a line perpendicular to the surface is

\* The absolute index of refraction assumes  $V_1$  to be the velocity of light in a vacuum.

drawn, the point  $c$  (or  $c'$ ) where it cuts the second circle is a point of the refracted ray  $OD$  (or  $OD'$ ).

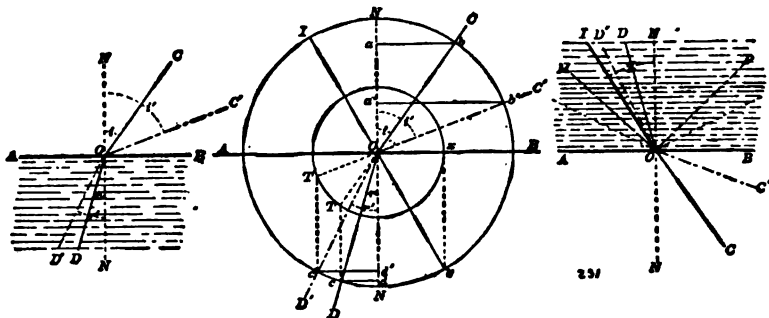
### Total Reflection.

If the angle of refraction is greater than the angle of incidence, as is the case when light travels faster in the second medium,

FIG. 229.

FIG. 230.

FIG. 231.



there is a so-called "critical" angle of incidence for which the angle of refraction is  $90^\circ$ ; that is, the refracted ray travels along the border surface. For any angle of incidence greater than this the light is totally reflected.

In Fig. 231 constructed on the same values as Figs. 229 and 230 rays like  $DO$  and  $D'O$  follow paths  $OC$  and  $OC'$  in the second medium, but some ray  $IO$  at the critical angle  $Z$  follows the path  $OB$ . All rays incident at greater angles than  $Z$ , such as  $MO$ , fail utterly to penetrate the second medium and are totally reflected as along  $OP$ .

The value of the critical angle is easily found from the indices of refraction of the two media, let  $n$  be that of the first, and  $n'$  that of the second, then  $n \sin i = n' \sin r$ , but if  $r$  is  $90^\circ$   $\sin r = 1$ , that is,  $n \sin i = n'$  or  $\sin i = \frac{n'}{n}$ . If the second medium is air

$n' = 1$  and the index of refraction of the first medium is  $n = \frac{1}{\sin i}$ .

### Dispersion.

When white light passes obliquely from one medium into an-

\* The ray at the critical angle is found graphically by drawing a tangent at  $x$ , Fig. 230, thus finding  $y$  a point of the desired diameter.

other, it is decomposed into a spectrum consisting of many kinds of light which are differently colored.\*

These component so-called monochromatic lights have each a different wave-length† which can be closely calculated. For instance, in millionths of a millimeter some prominent colors are: Violet  $H_1$  393.3, Blue  $F_1$  486, Green  $E$  526.9, Yellow  $D_1$  589.5, Red  $C$  656.2, Red  $A$  760.4.

With nearly all substances the shorter the wave-length the greater the refraction of the light, that is, the violet is most bent, the red least. It follows therefore that indices of refraction differ with the light used and should be obtained with monochromatic light.

#### OPTICAL GROUPS.

According to their optical symmetry crystals may be classified as:

*Isotropic.* Isometric.

*Anisotropic, Uniaxial.* Hexagonal and tetragonal.

*Anisotropic, Biaxial.* Orthorhombic, monoclinic, and triclinic.

#### THE OPTICALLY ISOTROPIC CRYSTALS.

Any normal isometric crystal shows the same optical properties in all directions, and is therefore optically isotropic.‡

Ignoring a few salts which crystallize in class 28, p. 66, and are circularly polarizing in all directions the following statements hold:

**The Index of Refraction** of any isometric crystal is a constant for all directions of transmission.

**Absorption** increases with the thickness and may be selective, giving color, but in any one crystal equal thicknesses in different directions give equal absorption and the same color tint.

That is, the optical tests on isotropic crystals are limited to color, index of refraction and *absence* of double refraction.

\* With plane parallel plates the light emerging from the second surface is parallel to the entering light and the color is not noticed. With a prism of proper angles the divergence is increased at the second surface of contact and a spectrum obtained.

† The distance light advances during a complete vibration is called its wave-length.

‡ Isotropic media behave alike in all directions with regard to light phenomena. Most liquids and glasses are isotropic.

### THE GENERAL PROPERTIES OF ANISOTROPIC CRYSTALS.

Anisotropic media do not behave alike in all directions.

As all crystals except those of the isometric system show different optical behavior in directions not parallel they are said to be *optically anisotropic*.

All anisotropic minerals are doubly refracting in most directions but possess either one or two directions of single refraction known as optic axes.

### DOUBLE REFRACTION AND POLARIZATION IN CALCITE.

That a ray of ordinary light entering calcite emerges as two rays of polarized light may be demonstrated as follows:

A moderately thick calcite\* cleavage, Fig. 232, is mounted with a rhombic face vertical and so that it can be revolved about a horizontal axis perpendicular to this face, Fig. 233.

A horizontal ray of light, *IT*, Fig. 234, is allowed to fall upon the vertical face. It passes through the calcite and emerges as two rays, one, *TO*, undiverted from its course, as would happen with ordinary refraction and perpendicular incidence, while the other, *TE*, has undergone some "extraordinary" refraction. On

FIG. 232.

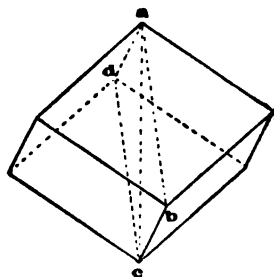


FIG. 233.

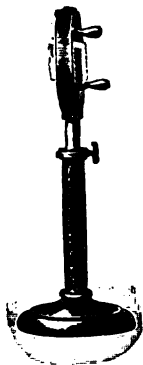
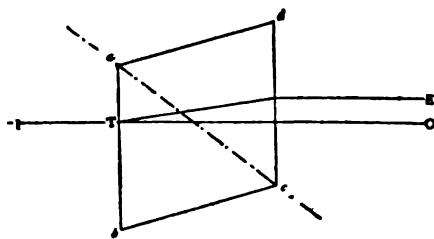


FIG. 234.



revolution of the calcite the diverted or extraordinary ray, *TE*, appears to revolve around the ordinary ray, *TO*, at a fixed distance

\* Double refraction in calcite was described in 1670 by Erasmus Bartholin, of Copenhagen, one year after Steno's announcement of the constancy of corresponding angles in quartz. That all its optical behavior corresponded to a double shelled ray surface was discovered by Huyghens in 1678.

from it and both evidently remain in a plane-parallel to the plane *abcd* through the short-diagonal, Fig. 232.

The two rays also appear to be of approximately equal brightness and not to change during the revolution of the calcite.

**Proof that the Rays are not Common Light.**

If the two rays *TO* and *TE* are common light then by shutting off one and allowing the other to go through a second calcite rhomb mounted like the first there should again result two rays of essentially equal brightness for all stages of rotation of the calcite rhomb. *This however is not the case.*

If *TO*, the ordinary ray, is used as a source, then, when the short diagonals of the vertical faces of the two calcite rhombs are parallel only an ordinary ray is seen, when they are crossed only an extraordinary, between these positions there are always two rays which alternately wax and wane and are only equal when the short diagonals are at  $45^\circ$  to each other.

Also if *TE*, the extraordinary ray, is used as a source there is a similar series of results, but the relative positions of the two calcites for any particular result have changed by  $90^\circ$ . That is, an ordinary ray is seen when the short diagonals are crossed, and an extraordinary ray when they are parallel and for any intermediate position, the intensities of the two rays have been reversed.

The rays *TO* and *TE* therefore differ from common light and differ from each other by some  $90^\circ$  relation.

Transmission in other directions in calcite gives similar results, but with this difference, that for the same thickness the divergence of *IO* and *IE* differs from a maximum for transmission at right angles to the three-fold symmetry axis to zero for transmission parallel to it.

**Theory to Explain Double Refraction of Calcite.**

The few facts stated show that the results depend upon the crystal structure of the calcite. If it is assumed that this structure is such that the vibrations of any entering ray\* are converted

\* The different effects of the same structure on common light and on a ray from the first calcite fit in with this theory. For the rapidly changing orientation of the vibrations in common light yield rapidly changing components and an average essentially equal "brightness" for the two rays for all positions, whereas the fixed vibration direction of the "polarized ray" yields varying components as the relative positions of the calcites change.

into two sets of straight-lined vibrations, one parallel to  $abcd$ , Fig. 232, one at right angles thereto, all the results of the experiment may be graphically shown for different relative positions of the two calcites by representing these directions of vibration by straight lines and the intensities by the lengths of these lines.

Assuming that the vibrations of the extraordinary ray are parallel  $abcd$  and that of the ordinary at right angles thereto, the problem is simply to resolve the initial ray, represented by a line definite in length and parallel (or at right angles) to the short diagonal of the first calcite, into components parallel and at right angles to the short diagonal of the second calcite.

### Double Refraction not Limited to Calcite.

By other methods later to be elaborated it may be shown that double refraction is a common property of all crystals except the isometric and that the vibrations of any entering ray are converted by any crystal (not isometric) into two sets of straight-lined vibrations in planes at right angles to each other, the directions of these planes being dependent on the crystal.

### THE OPTICALLY UNIAXIAL CRYSTALS.

#### Optic Axis.

In every crystal of the hexagonal or tetragonal system the direction of the principal crystallographic axis ( $c$ ) is a direction either of single refraction or of circular polarization and the directions equally inclined to the crystallographic axis are optically equivalent.

The crystallographic axis  $c$  is therefore an Optic Axis.

#### Ray Surface.

The optical properties of a uniaxial crystal are best understood by considering the shape of the Ray Surface,\* which consists of two shells with a common center. One is a sphere, the other an ellipsoid of revolution, the axis of revolution being either the major or minor axis of the ellipse but always a diameter of the sphere. *It is also the optic axis.*

Evidently for every direction except that of the optic axis two rays are transmitted, an ordinary with a velocity indicated by

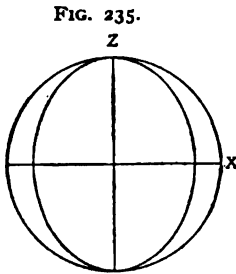
\* Assume one vibration of monochromatic light within a homogeneous medium and the transmission of this vibration in all directions along rays. At the end of any period the motion will have reached some definite point on each ray. The closed surface through these points is the ray surface of the substance.

the sphere radius and an extraordinary with a velocity indicated by the corresponding radius vector of the ellipsoid, and the greatest difference of velocity exists for the direction of transmission at right angles to the optic axis.

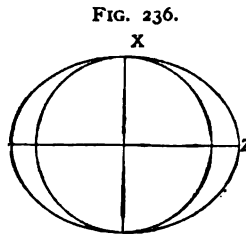
#### Positive and Negative Character of Ray Surface.

The spherical shell may surround the ellipsoid shell or *vice versa*. The former combination is called a positive ray surface, the latter a negative.

In the positive ray surface, Fig. 235, the constant ordinary ray is evidently faster for any directions of transmission than the extraordinary and the slowest ray is evidently the extraordinary transmitted at right angles to the axis of rotation or optic axis. In the negative ray surface, Fig. 236, this is reversed and the



Section of Positive Ray Surface.



Section of Negative Ray Surface.

*fastest* ray is the extraordinary ray transmitted at right angles to the optic axis.

If the direction of vibration of the fastest and slowest rays be denoted respectively by  $X$  and  $Z$  then, as indicated in the ray surfaces,

$Z$  is the axis of rotation or optic axis in a positive ray surface and  $X$  in a negative.

Or since the optic axis is the crystallographic axis  $\epsilon$  we may summarize:

$$\begin{array}{l} + \text{ when } Z \text{ parallel } \epsilon, \\ - \text{ " } X \text{ " } \epsilon. \end{array}$$

#### Indices of Refraction.

From what has just been said it follows that for any direction of transmission there is one constant index of refraction and for



any direction but the optic axis there is a second index varying with the direction. Finally that the indices of refraction obtained for a direction at right angles to the optic axis are the largest and smallest obtainable and are called *the principal indices*.

The principal indices are most conveniently, and in conformity with the usage in biaxial crystals, denoted by  $\gamma$  and  $\alpha$ .  $\gamma$ , the largest index, is the index of the slowest transmitted ray, with vibration direction parallel  $Z$ ;  $\alpha$ , the smallest index, is the index of the fastest transmitted ray with vibration direction parallel  $X$ . Hence the relations may also be stated: *Positive* when vibration of  $\gamma = \epsilon$ , *Negative* when vibration  $\alpha = \epsilon$ .

#### **"Birefringence" and Phase Difference.**

The difference between the principal indices is called the birefringence or strength of double refraction. In different crystals of the same species it is more constant than the indices themselves. For any direction except that of the optic axis, both rays are retarded but one more than the other. There must therefore develop a phase difference increasing with the thickness.

If the direction is at right angles to the optic axes

Phase difference = thickness  $\times$  birefringence or  $\Delta = t(\gamma - \alpha)$ .

#### **Vibration Directions.**

For any direction of transmission the two rays will possess definite directions of vibration at  $90^\circ$  to each. When these can be compared with a crystallographic direction they are useful. One will always be in the plane through the optic axis.

#### **Circular Polarization.**

In quartz and cinnabar crystals the light transmitted in the direction of the optic axis is "circularly polarized."

That is ordinary polarized rays with vibration in straight lines in a known plane emerge with their vibrations in a different plane.

The angle of rotation is dependent on the thickness and for quartz amounts to  $24^\circ$  per millimeter for sodium light.

A thin section or fragment of basal quartz of say .03 to .04 mm. thickness would therefore develop less than one degree of rotation.

In other directions these minerals behave nearly, though not exactly, like ordinary uniaxial minerals.

#### **Absorption and Pleochroism.**

In symmetry if not in degree the absorption phenomena correspond to the transmission. The absorption of the ordinary ray

being independent of the direction of transmission, while that of the extraordinary varies with the inclination to the optic axis, but is constant for the same angle and differs most from that of the ordinary for transmission normal to the optic axis.

#### THE OPTICALLY BIAxIAL CRYSTALS.

##### Optic Axis.

In orthorhombic, monoclinic and triclinic crystals, no true optic axes exist because there is no direction of optical isotropy.

There are, for monochromatic light\* and constant temperature, two directions of single refraction, and as in most cases the uniaxial optic axis is a direction of single refraction these by a strained analogy are called optic axes, for light of that wave-length.

They are determinable directions and therefore useful and their very variations for temperature and wave-length constitute tests.

##### The Biaxial Ray Surface.

For a given temperature a monochromatic light motion starting from a point within a biaxial crystal reaches at any moment a very complicated double ray surface which is symmetrical only to three lines at right angles called *principal* vibration directions, and three planes, each through two of these lines, called *optical principal sections*.

Two of the three lines are always the vibration directions of the fastest and slowest rays, the third is at right angles to these and is the vibration direction corresponding to some ray of intermediate velocity.

It may be noted that the planes and axes of geometric symmetry are always† optical principal sections or principal vibration directions.

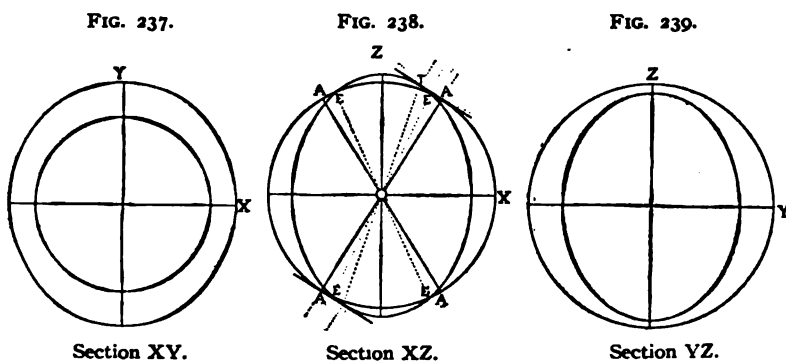
In conformity with the convention of the uniaxial crystals let the vibration directions of the fastest and slowest rays be

\* The directions of single refraction or so-called optic axes depend upon the principal indices of refraction, hence change both with wave-length and temperature, the amount of change varying from a few minutes to many degrees.

† Thus in *Orthorhombic Crystals* the principal vibration directions and optical principal sections are constant for all colors, in *Monoclinic Crystals* one principal vibration direction and one optical principal section are fixed for all colors, the others vary with the wave-length; in *Triclinic Crystals* there are no principal vibration directions or principal sections which are constant for all colors.

denoted by  $X$  and  $Z$  respectively and let  $Y$  represent a direction at right angles to  $X$  and  $Z$ .

The shape of the ray surface may be judged from the shape of the optical principal sections  $XY$ ,  $XZ$ , and  $YZ$ .



*Optical Principal Section  $XY$* , Fig. 237, cuts the two shells of the ray surface as a circle within an ellipse with radius, major and minor axes respectively slowest, fastest and intermediate velocities.\*

*Optical Principal Section  $YZ$* , Fig. 238, cuts the two shells of the ray surface as an ellipse within a circle with radius, major and minor axes respectively fastest, intermediate and slowest velocities.

*The Optical Principal Section  $XZ$* . This is the most important section because it is the plane of the optic axes. It cuts from the ray surface an ellipse and a circle which intersects the ellipse in four symmetrically placed points,  $E$ , Fig. 239. The radius, major and minor axes are respectively the intermediate, fastest and slowest velocities.†

Near but not *at* the points  $E$ ; common tangent planes can be drawn to each shell. The directions,  $AA$ , normal to these common tangent planes are directions of single refraction, that is, are the

\* These velocities are proportionate to the reciprocals of  $\alpha$ ,  $\beta$ ,  $\gamma$ , the indices of refraction for rays with vibrations parallel  $X$ ,  $Y$  and  $Z$ .

† The light *emerging* on the direction  $AA$  is not simply the singly refracted ray which has travelled in the crystal in the direction  $AA$  but all that diverging cone of rays with  $O$  as a point and the circle of contact of the tangent plane as a base. Each ray has its own direction of vibration.

so-called optic axes and the rays travelling in these directions have the intermediate velocity (or index of refraction  $\beta$ ).

#### Positive and Negative Character of Ray Surface.\*

In  $XZ$ , the plane of the optic axes,  $X$  and  $Z$  bisect the angles between these axes. If the acute bisectrix is  $Z$  ( $Bx_a = Z$ ), the ray surface is said to be *positive*.†

If the acute bisectrix is  $X$  ( $Bx_a = X$ ), the ray surface is said to be *negative*.

#### OPTICAL PROPERTIES AND CONSTANTS OF BIAxIAL CRYSTALS.

These can most simply be stated by reference to the uniaxial crystals.

#### Indices of Refraction.

The principal indices are for rays with vibration directions parallel the three axes of symmetry; one will be  $\gamma$  the largest index anywhere obtainable, one will be  $\alpha$ , the smallest, the third will be  $\beta$ , that of a ray with vibration directions at right angles to these.

For other directions intermediate values are obtained. There is no constant index.

#### Birefringence.

The difference between the largest and smallest index ( $\gamma - \alpha$ ) is the birefringence of the crystal.

#### Optic Axial Angle.

The angles between the optic axes can be measured—the acute angle is designated by  $2V$ .

#### Vibration Directions.

As with the uniaxial these lead to a knowledge of the symmetry.

#### PRODUCTION OF PLANE POLARIZED LIGHT.

Plane polarized light may be produced from common light:

\* This conforms strictly to the usage in the uniaxial which is a special case of biaxial with the angle between the optic axes zero, the acute bisectrix being in the direction  $c$ .

† In terms of principal indices these might be written *Positive*, vibration of  $\gamma = Bx_a$ , *Negative*, vibration of  $\alpha = Bx_a$ .

1. By reflection from a non-metallic surface.\*
2. By double refraction and absorption.†
3. By double refraction and total reflection.

### Nicol's Prisms.

The third method is most used and while many polarizing prisms exist all are based on the prism described by William Nicol‡ in 1828.

I It may be briefly described as consisting of a cleavage of Iceland spar (calcite) with a length about three times its breadth.

Let  $aBdC$ , Fig. 240, be a principal section through the optic axis  $XY$  and the short diagonals  $aB$  and  $Cd$  of opposite small cleavage faces.

To secure the needed directions these small faces, at  $70^\circ 52'$  and  $109^\circ 8'$  to the edge  $BD$ , are ground away and replaced by faces, indicated by  $AB$  and  $CD$  at  $68^\circ$  and  $112^\circ$ , to the edge. The prism is then cut through by a plane through  $AD$  at right angles both to the new terminal faces and to the principal section. The parts are carefully polished and cemented by Canada balsam, the index of refraction of which is about 1.54.

The index of refraction of the ordinary ray is 1.658, that of the extraordinary ray varies with the direction of transmission between 1.486 and 1.658. For instance, the ray transmitted parallel to  $DB$  has an index 1.516.

The general effect therefore of such a construction is that any incident ray  $IE$ , Fig. 240, on entering is split into two rays. The ordinary ray, with an index of refraction of 1.658, if incident at

\* The reflected ray is perfectly polarized only when it is at right angles to the refracted ray. For this *particular angle of incidence* ( $\tan i = n$ ). The vibrations are at right angles to the plane through incident and reflected ray. With glass a series of parallel plates are used each plate increasing the proportion of polarized light.

The device is inexpensive but it is difficult to obtain enough perfectly polarized light because of the small angle to which the incident rays must be limited.

† *Double refraction and absorption.* Certain substances, such as tourmaline, absorb one ray much more rapidly than the other, and a thickness can be chosen for which one ray is totally absorbed, the other being partially transmitted with vibrations all in one plane.

The very simple polariscope called the tourmaline pincers depends on this principle but the light is colored.

‡ Edinb. New Phil. Jour., VI, 83-94.

the balsam at an angle greater than its critical angle, follows some path  $EJ$  and is totally reflected at the balsam along  $JH$  and absorbed by the blackened walls about the nicol.

The extraordinary ray, however, follows some path  $EF$  and if its index is less than 1.54, is simply diverted a little by the balsam, say, along  $FS$ , and thereafter following the path  $SG$  parallel  $EF$  emerges travelling parallel the incident ray  $IE$  but *plane polarized and, according to the assumption made on describing double refraction*

FIG. 240.

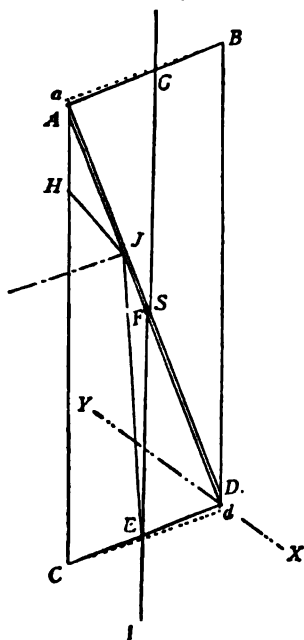
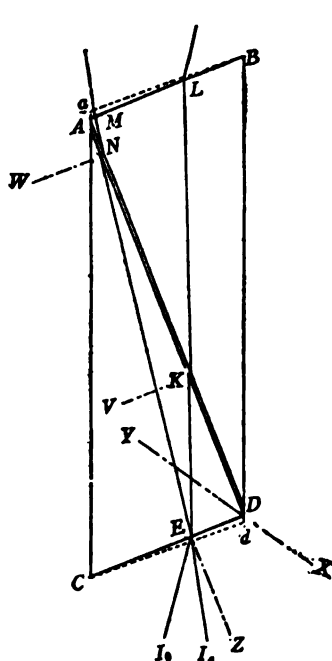


FIG. 241.



*in calcite, with its vibration direction in the plane of  $AB$  the short diagonal of the face of the nicol.*

Fig. 240 shows the nicol section with light incident in the direction  $IE$  parallel the length of the nicol. In Fig. 241 the construction considers light incident at any angle and shows that only the rays between  $I_0$  and  $I_e$  will yield pure extraordinary rays, since these are furnished only by light rays incident at the balsam *between* the critical angles of the ordinary and

extraordinary ray.\* This so-called "opening angle" of the nicol is about  $25^\circ$ .

The critical angle of the ordinary ray is  $EKV = 68^\circ 13'$ , Fig. 241, corresponding to an incident ray  $I_0$  at  $37^\circ 59'$  to  $EZ$ . Both components of any ray incident at an angle greater than  $37^\circ 59'$  would be transmitted.

The critical angle of the varying extraordinary ray is  $ENW = 81^\circ 34'$ , corresponding to an incident ray  $I_e$  at  $13^\circ 12'$  to  $EZ$ . Neither component of any ray incident at an angle less than  $13^\circ 12'$  would be transmitted. That is, the useful or opening angle of the nicol is  $I_0EI_e = 37^\circ 59' - 13^\circ 12' = 24^\circ 47'$ .

This opening angle may be increased considerably by different constructions.

For instance, the Hartnack-Prazmowsky prism is calcite with the end faces at right angles to the others and with linseed oil instead of balsam. In others the material is different. Sodium nitrate prisms have been made, but while optically good were hygroscopic. Combinations of glass and calcite are successful as polarizers but not as analyzers because they are not achromatic. In some devices the ordinary ray is transmitted instead of the extraordinary.

#### THE FUNDAMENTAL PHENOMENA BETWEEN CROSSED NICOLS.

##### Crossed Nicols.

The term nicol is hereafter used to designate *any* form of polarizer. If two nicols are placed so that the light from one reaches the other, the light will go through the second unchanged if the faces of the nicol are parallel, but if one is rotated the light emerging from the second nicol will vary in intensity with their relative position.

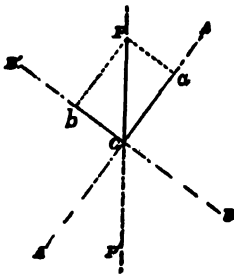
Let  $PP'$  Fig. 242 be the direction of vibration of light from the first nicol and  $CP$  its amplitude, then if  $AA'$  is the direction of vibration of the extraordinary ray in the second nicol and  $BB'$  that of the ordinary ray the components of  $CP$  in these directions will be  $Ca$  and  $Cb$ , of which the former will be transmitted, the latter totally reflected at the balsam.

\* For elaborate discussion see Johannsen's "Manual of Petrographic Methods," pp. 158-175.

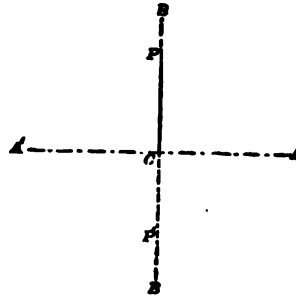
If the rotation is clockwise  $C_a$  will decrease and at  $90^\circ$  of rotation, with *crossed nicols*, it will be zero, that is, none of the light from the first nicol will emerge from the second nicol and the field will be dark.

As the rotation is continued  $Ca$  will increase until at  $180^\circ$  it again equals  $CP$  and so on. The first nicol is often called the Polarizer, the second the Analyzer.

**FIG. 242.**



**FIG. 243.**



The fundamental phenomena between crossed nicols upon which all optical tests rest may be described under the headings Depolarization, Extinction and Interference and they may be illustrated by any simple combination of polarizer and analyzer as tourmaline pincers or two nicols prisms set in a hole bored in a block of wood and a slit crossing the hole at right angles for the insertion of the crystal plate.

### Depolarization.

If a plate of glass or a section of an isometric crystal is placed between crossed nicols, the dark field remains dark. But if a section of a doubly refracting crystal is so inserted, the field is in general illuminated because any ray of light from the first nicol emerges from the section as two parallel rays with vibrations at right angles to each other, each of which would furnish a component in the direction of vibration of the second nicol. In other words, the dark field would be illuminated, although the nicols remain crossed.

**Extinction.**

If any doubly refracting crystal section is revolved between the nicols in its own plane until its vibration directions are parallel



to the vibration direction of the nicols the light from the first nicol will be transmitted without change through the section but on reaching the second nicol will be stopped because its vibration direction is at right angles to the vibration direction of the second nicol. That is, the light, which in general passes through the described combination of crossed nicols and crystal section, will be shut out or extinguished every  $90^\circ$  or four times during a revolution of the section in its own plane.

### Interference of Monochromatic Polarized Light Between Crossed Nicols.

Two rays of polarized light of the same wave-length, following the same path and with vibrations in the same plane will combine

FIG. 244.

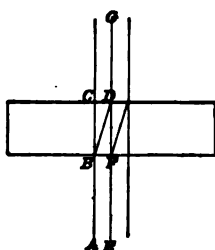
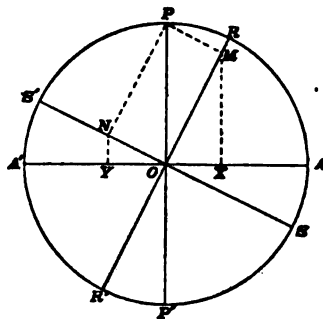


FIG. 245.



or "interfere," their vibrations either supplementing or opposing each other according to the so-called phase difference of the rays.

For instance, if the light incident at the lower surface of a section of a doubly refracting plate shown in Fig. 244 is polarized, monochromatic and parallel, interference will take place between crossed nicols as follows:

The less refracted ray  $FD$  from the incident ray  $EF$  and the more refracted ray  $BD$  from the parallel incident ray  $AB$  will, after emergence, follow the same path  $DG$  (parallel to the incident rays) but their vibrations will take place in planes at right angles to each other.

There will in general be a phase difference between  $FD$  and  $BD$  because they are unequal in length, different in vibration direction,

and, having encountered different structures, have been retarded unequally.

Reaching the analyzer the vibrations of  $FD$  and  $BD$  will be brought into the same plane, each furnishing a component in the direction of the vibration plane of this second nicol, and therefore, they will combine or "interfere."

Similarly from *each* point of the upper surfaces of the crystal section there will emerge two rays with the same phase difference as  $BD$  and  $FD$  which will be brought by the analyzer to the same "interference."

For the understanding of interference between crossed nicols two important limit cases must be considered.

Denote the difference in retardation of the two rays by  $\Delta$  and the wave-length of light by  $\lambda$  then:

1. If  $\Delta = \lambda, 2\lambda, 3\lambda, \dots, n\lambda$  the two components following the same path will oppose and exactly neutralize each other, the light will be stopped and darkness will result for all positions of the crystal section.

2. If  $\Delta = 1/2\lambda, 3/2\lambda, 5/2\lambda$  (or any odd multiple of  $1/2\lambda$ ), the two components following the same path will supplement each other and the field be most strongly illuminated for all positions of the crystal section.

The proof for the first statement is as follows: Let  $PP'$ , Fig. 245, represent the direction of vibration and  $OP$  the intensity of the light from the first nicol. Let  $RR'$  and  $SS'$  represent the vibration (or extinction) directions of the doubly refracting plate and  $AA'$  the direction of vibration direction of the second nicol.

Then at the instant of entering the plate  $OP$  is resolved into components  $OM$  and  $ON$ .  $OP$ ,  $OM$  and  $ON$  will be the same\* phase and evidently also when one of the two has gained relatively, just a wave-length (or 2 or 3, etc., wave-lengths) their phases will still be alike, that is, the components of  $OM$  and  $ON$  in the vibration direction  $AA'$  are  $OX$  and  $OY$  equal† and in opposite directions.

*Practical Confirmation.*—A wedge of doubly refracting substance, for instance, a little wedge of gypsum made by shaving down a cleavage with a sharp knife or better by rubbing it down will show, in monochromatic light under low magnification, dark bands at regular intervals, which vary in distance apart with the color of the light used and correspond to differences between the emerging rays of one, two, three, etc., wave-lengths.

\* If  $OP$  at end of its vibration then so are  $OM$  and  $ON$ , if in middle so are they.

† Because they are horizontal projections of equal parallel lines  $OM$  and  $PN$ .

### INTERFERENCE COLORS WITH WHITE LIGHT.

The "retardation"  $\Delta$  has a definite numerical value dependent on thickness, direction and material. For a given section it differs only slightly for different wave-lengths of light. If therefore white light, which is composed of many rays of different wave-lengths, is used as a source of light, the retardation  $\Delta$  may be at the same time: (a) approximately a multiple of the wave-length of light of one or more colors, which would therefore be shut out; (b) closely an odd multiple of the half wave-lengths of other colors leaving these at nearly their full intensity, and (c) intermediate, with still other colors.

The resultant so-called interference color shown by the section of a doubly refracting substance between crossed nicols would be the combination of what is left of the different monochromatic colors.

#### The Interference Color Corresponding to a Given Value of $\Delta$ .

If  $\Delta$  be divided successively by the wave-lengths of the different colors and the quotients considered, those colors will be wholly or nearly shut out for which the quotients are closely 1, 2, 3, 4, etc., and those colors will be nearest their full values for which the quotients approach  $1/2$ ,  $3/2$ ,  $5/2$ , etc. For quotients of intermediate values the colors will be partially shut out.

If then due allowance is made for the relative intensities of the spectrum colors the interference color will be evident.

Using five prominent colors only an approximate determination may be made either graphically or by direct calculation.

*Graphically.*—In Fig. 246 the construction is as follows:

The first vertical line is the  $\Delta$  scale divided into spaces representing 100  $\mu\mu$  (millionths of a millimeter).

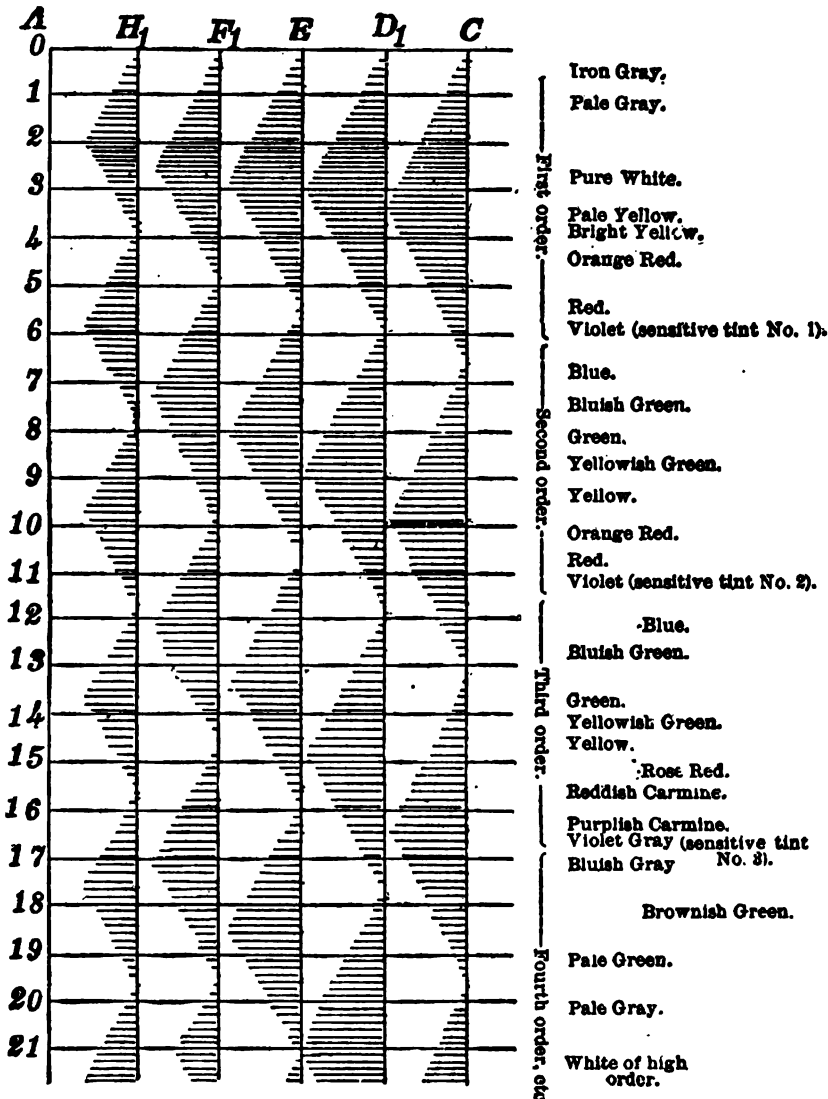
The remaining five vertical lines are divided respectively into spaces proportionate to the half wave-lengths (in millionths of a millimeter) for  $H_1$  (violet), 393.3;  $F_1$  (blue), 486.0;  $E$  (green), 526.9;  $D_1$  (yellow), 589.5;  $C$  (red), 656.2;  $A$  (red) 760.4.

Taking any length as indicating maximum light draw lines of this length opposite 1, 2, 3, 4, wave-lengths. Draw parallel lines regularly diminishing to the length zero opposite  $1/2$ ,  $3/2$ ,  $5/2$ , etc., wave-lengths.

The lines represent the proportion of the violet, yellow, etc., present. They do not show the coloring intensities which in the order of colors stated are roughly 0, 1, 2, 3, 6, 2.

A fair approximation therefore to the interference color corresponding to any value of  $\Delta$  will result by following a horizontal

FIG. 246.



straight edge across from this value and noting the relative lengths of the horizontal lines.

*By Calculation.*—For instance let  $\Delta = 900 \mu\mu$  (millionth of a millimeter).

$$H_1\text{—Violet } \frac{900}{393} = 2.29 \text{ over } 1/2 \text{ present.}$$

$$F_1\text{—Blue } \frac{900}{486} = 1.85 \text{ about } 3/10 \text{ present.}$$

$$E \text{ —Green } \frac{900}{527} = 1.70 \text{ about } 1/2 \text{ present.}$$

$$D_1\text{—Yellow } \frac{900}{590} = 1.52 \text{ almost all present.}$$

$$C \text{ —Red } \frac{900}{656} = 1.37 \text{ about } 3/4 \text{ present.}$$

That is, the color is made up of almost all the yellow,  $3/4$  of the red, about  $1/2$  of the violet and green and  $3/10$  of the blue.

Multiplying by the relative intensities for each color, as stated in graphical method, the following proportions result: Violet 0, blue  $3/10$ , green 1, yellow 6, red  $3/2$ . That is, yellow greatly predominates. The red more than balances the green and the blue and the remaining red tints the dominant yellow, forming orange.

#### The Interference Color Scale.

The interference colors grade from black for  $\Delta = 0$ , to colors not clearly distinguishable from white with  $\Delta$  beyond  $2,000 \mu\mu$ .

Because the colors repeat to some extent periodically they are divided into so-called "Orders,"\* the convenient transition color between orders being a so-called sensitive violet because very minute changes in  $\Delta$  result in decided changes to blue or red.

| Order.      | Last Color.                                | Value.         |
|-------------|--|----------------|
| First.....  | Sensitive violet, No. 1.....               | 575 $\mu\mu$   |
| Second..... | Sensitive violet, No. 2.....               | 1,130 $\mu\mu$ |
| Third.....  | Sensitive violet, No. 3 (violet gray)..... | 1,652 $\mu\mu$ |

In Fig. 246 the names of the principal colors of the color scale are approximately opposite the corresponding values of  $\Delta$ .

*The first order colors* start with black and pass through shades

\* These are not quite Newton's orders, which end respectively at  $\Delta = 551, 1101$ , and  $1652$ . This division gives no sensitive violet in the first order, one in the second, and two in the third.

of gray to nearly pure white\* at  $\Delta = 250 \mu\mu$ . Beyond this the shorter waves are more completely shut out and the yellow orange and red reach a maximum.

*The second order colors* are in general bright spectrum colors—Indigo, blue, green, yellow, orange, red.

*The third order colors* are paler and more complex because with increasing values  $\Delta$  becomes an approximately perfect multiple of  $1/2\lambda$  for an increasing number of wave-lengths. For example:  $\Delta = 1500$  is  $5/2\lambda$  for orange red,  $7/2\lambda$  for indigo,  $3\lambda$  for green,  $2\lambda$  for red,  $4\lambda$  for violet. The resultant total effect is between carmine and purple.

*The higher orders.*—With the still higher values for  $\Delta$  the paleness and indefiniteness of the colors are still more noticeable and beyond the fourth order the colors are usually grouped as “high order whites.”

### **The Polarizing Microscope and Its Adjustment.**

The modern polariscope for the study of crystals is the polarizing microscope. With the proper attachments it yields all the desired tests either with relatively large or microscopic quantities of material.

The simplest polarizing microscope necessarily includes the essentials of an ordinary microscope (a stand supporting a tube carrying objective and ocular, a platform or stage and means of focusing and illuminating), and in addition a nicol, “the polarizer,” below the object, to polarize the incident light, and another above the objective, “the analyzer” arranged to be thrown in or out and “crossed” with respect to the polarizer.

To these essentials may be added many devices and attachments for special purposes resulting in a highly complex piece of mechanism. For general work something between the two extremes is most satisfactory.

### **The Illuminating System.**

This consists of the mirror, and the condensing lens and sometimes a diaphragm.

*The mirror* has one plane face and the other concave. It may

\* For this value the diminished intensities of the colors are relatively nearly as in white light.

be tipped in any direction and usually has a limited up-and-down motion.

Its purpose is to reflect light from the source to the object. The plane mirror should be used for sunlight or for low magnifications, the concave for high magnifications without the condenser, for very high magnifications and interference phenomena the plane mirror and condensing lens.

*The condenser* or condensing lens illuminates the object with a cone of light. In some instruments it rests on the top of the polarizer, in others it is swung into position by a lever, being attached to the same system it is raised with the polarizer and at its highest point is practically level with the upper surface of the stage.

The principal use is in obtaining the so-called convergent light effects.

The best effects are obtained when the condenser\* is in focus; this often is at the highest point.

#### **The Polarizer and Analyzer.**

The nicols prism has been described in detail, p. 109. Two polarizing prisms called nicols are needed in the polarizing microscope. The lower, called "*the polarizer*," can be raised or lowered by lever or screw and swung or drawn aside. Usually it can be adjusted so that its plane of vibration is either parallel or diagonal to the cross hairs as in Fig. 247.

The analyzer is usually a flat-ended prism such as the Glan-Thompson placed above the objective and arranged to slide in and out of the microscope tube. It frequently can be rotated through  $90^\circ$ , as in Fig. 248, so that the plane of vibration may be placed cross or parallel to that of the polarizer.

In certain microscopes such as Fig. 248 both nicols can be rotated together instead of rotating the stage.

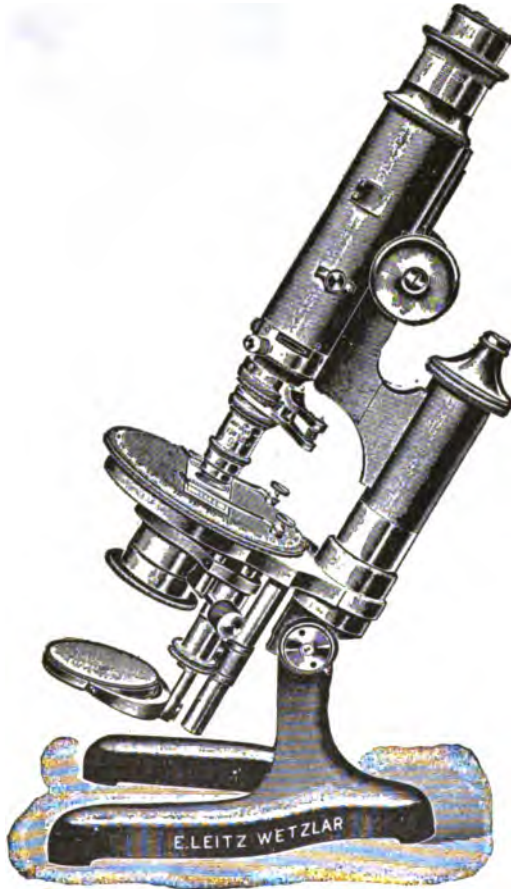
#### **The Objectives and Oculars.**

Different objectives and oculars are used in crystal work, never of very high power, the most used combinations varying in magnification from 50 to 400 diameters.

\* Focus on a section with a low power objective, turn plane mirror until some object, tree, window bar, etc., is in field. Raise and lower condenser until this image is sharp, then slightly rotate mirror.

*The objective* receives the light from the object, focuses it and produces a real image. Its magnifying power increases with the tube length of the microscope and its resolving power or power to make details visible increases with the number of rays coming

FIG. 247.



Leitz Microscope No. 30.

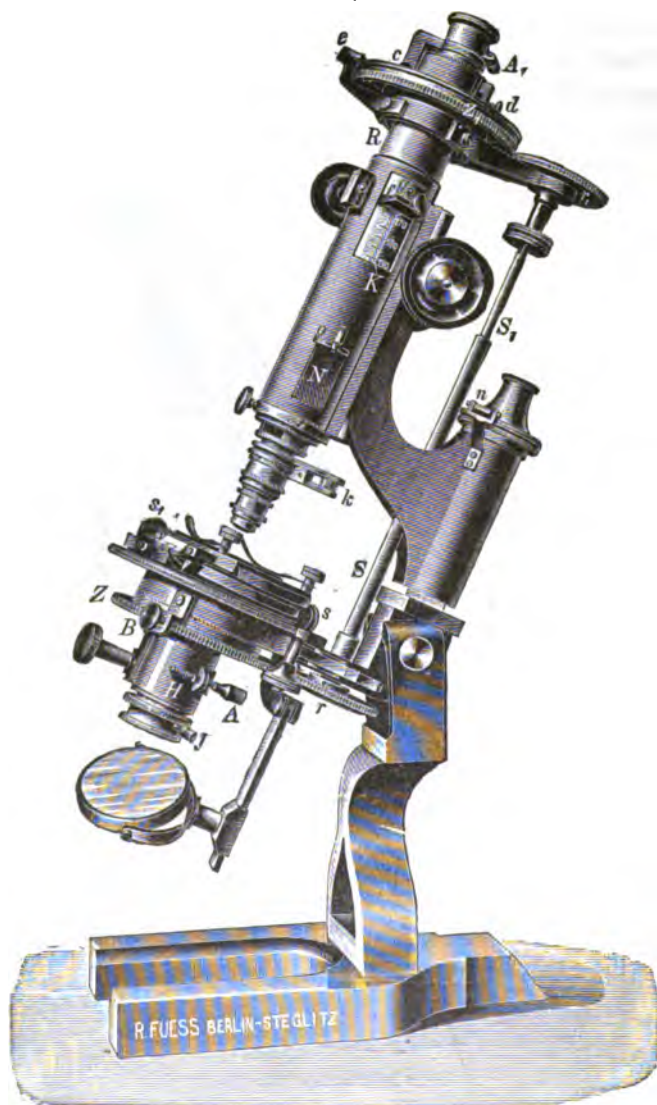
from the object and on its relative freedom from spherical\* and chromatic† aberration.

\* Unequal magnification in different parts of the field and haziness due to different focal lengths.

† Different focal lengths of light of different colors.



FIG. 248.



Fuess Microscope No. VI.

Objectives are usually numbered and sometimes marked in terms of the focal length ranging from low powers of 3 inch to high powers of  $1/12$  inch or less.

*Oculars.*—The ocular or eye piece most used is the Huyghens\* ocular made of two plano-convex lenses with their plane surfaces towards the eye, the lower or field lens collects the rays and lessens the spherical and chromatic aberration. The upper or eye lens connects the rays into parallel rays and gives an enlarged inverted image of the object. "Cross hairs" or micrometers are placed at the focal plane of the field lens. The cross hairs usually intersect in the line of sight at right angles and parallel to the vibration plane of the nicols.

To obtain high magnification it is generally better to use a high power objective and low or medium power eye piece as the higher power oculars cause indistinctness.

*The Field of View* with Huyghen's ocular is roughly in fractions of an inch five times the reciprocal of the magnifying power in diameters, *e. g.*, 50 diameters of the field is  $1/10$  inch.

#### **The Path of the Light and Formation of the Image.**

The object  $O_1$ , Fig. 249, receives rays from a mirror, these pass through the diaphragm  $CD$  and condenser system, then through the objective and cross at  $F_1$  and enter the lower or field lens of the eye piece giving a *real*† inverted image at  $O_2$ , which is enlarged by the upper or eye lens to the virtual and still inverted image at  $O_4$ .

The optical tube length of the microscope is  $\Delta$ , Fig. 249, the distance between the two foci  $F_1$  of the objective and  $F_2$  of the eye lens. The magnifying power of an objective increases with the tube length.  $L$  is the mechanical tube length usually 160 mm. and  $EP$  the eye point.

#### **The Mechanical Parts of a Polarizing Microscope.**

*The Stand.*—The support to which the other parts are attached. Usually with a heavy horse-shoe base.

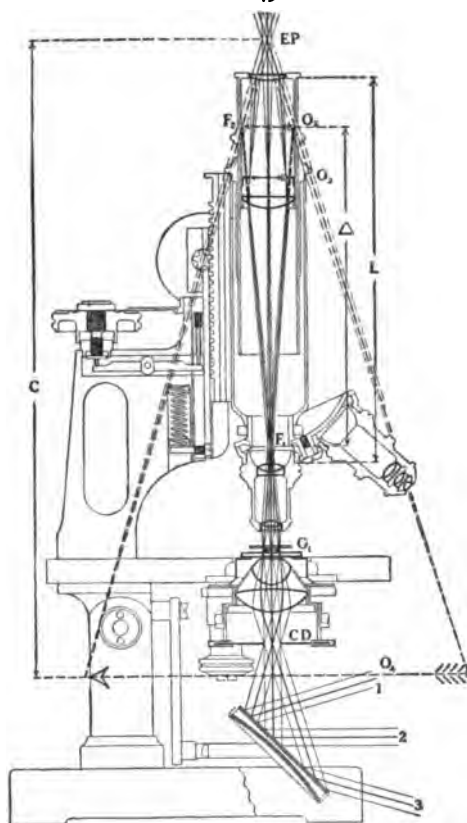
*The Stage.*—The simple stage is a circular disc, Fig. 247, with a central hole. It can be rotated about an axis coincident with

\* In the Ramsden ocular the convex sides of the two lenses face each other and the image is not inverted.

† The real image results when the object is further from the lens than the focal length. It is on the opposite side of the lens and can be projected. The virtual image results when the object is nearer the lens than the focal length. It can not be projected.

the line of sight. In some instruments it is permanently centered, in some adjustable. It should be graduated so that angular rotations can be read to fractions of a degree. In more elaborate instruments it has sliding screws  $ss'$  Fig. 248, and other accessories.

FIG. 249.



After Bausch and Lomb.

### Body Tube and Draw Tube.

These carry most of the optical parts, the draw tube sliding in the body tube. In both 247 and 248 the draw tube is graduated to show the "optical tube length,"  $\Delta$ .

### Coarse and Fine Adjustment.

*The coarse adjustment* is usually a rack and pinion motion of the drawing tube with respect to the stand while the *fine adjustment*

is by a micrometer screw with a graduated milled head, *n*, Fig. 248, the value of one division usually being .01 mm.

#### Centering Screws.

Two screws producing motion at right angles and attached either to the objective holder, as in Fig. 247, or to the stage.

#### Objective Holder.

This is usually a clutch or clasp, *k*, Fig. 248, which is really a pair of steel tongs which grips a collar on the objective between its jaws. It is always advisable to give the objective a slight twist after inserting it.

#### Slots for Accessories.

A slot is always provided just above the objective for the insertion of the so-called test plates (quarter undulation mica plate, gypsum red of first order, quartz wedge, etc.). The better instruments have a second slot in the telescope above the analyzer for the introduction of a Bertrand lens, *f*, Fig. 248, by which the interference figures are made visible.

### ADJUSTMENTS OF THE MICROSCOPE.

The resolving power, definition and freedom from much aberration are judged by means of selected slides, such as those of diatoms, using a weak ocular and the light from a white, thinly clouded sky.

#### Focusing.

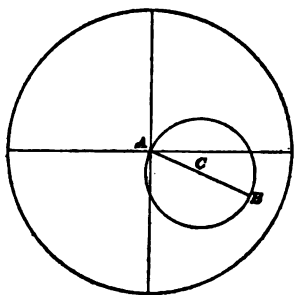
This should be tried first with a medium power objective, the focal length of which may be 1/4 inch or more. Set the objective lower than this and *focus upward*. In using a high power "place the eye on a level with the stage" and looking toward a window lower the objective until only a thin film of light remains between the cover glass and the lens and then *focus upward*. When practicable, use a low power as a finder.

#### Centering.

Focus on a minute grain and move the glass until the grain coincides with *A*, Fig. 250, the intersection of the cross hairs. Revolve the stage 360° and note the orbit of the grain. The center (*C*) of the orbit is the center of rotation. When the grain is at *B*,

that is, after  $180^\circ$  rotation, move it half-way to *A* by the two adjustment screws and the other half by moving the object glass. Repeat the operation.

FIG. 250.



#### **Determining Vibration Direction of Lower Nicol.**

In the original nicols prism the vibration direction is that of the short diagonal. In other forms this direction needs to be determined because known distinctions can then be made between the indices of refraction, the absorption directions, etc. With the upper nicol out rotate a section of biotite showing the cleavage cracks until the position of maximum darkness is reached. The plane of vibration of the lower nicol will then be parallel to the cleavage cracks.

Or use a thin dark-colored tourmaline which is darkest when the vibration plane of the nicol is perpendicular to its optic or  $c'$  axis. Or, removing the polarizer, view the light reflected from a plane polished surface the surface will appear darkest when the vibration plane of the nicol is perpendicular to it.

#### **Determining Magnification.**

The magnifying power of any combination of lenses is the product of the magnifying power of the objective and eye piece used. A table giving the magnification for each combination should accompany each microscope.

It is usually stated in diameters and can be obtained approximately by placing on the stage a cover glass with lines ruled a known distance apart, focusing on this and obtaining its image on a ground glass 10 inches above the eye-point. Then the magnification in diameters is equal to the distance apart of two lines of the image divided by the distance apart of the same two lines on the cover glass. If an Abbe drawing apparatus is available the lines may be projected by this and sketched and their distance apart measured.

#### **Using a Microscope.**

The student should sit upright with the microscope directly

in front and both hands free for manipulation. Either eye may be used, *the other being kept open*. A glare should be avoided and that amount of light used which shows the structure.

Dust should be removed from lenses and nicols by a soft brush or by blowing and wiping with clean lens paper. Sudden changes of temperature and direct sunlight are to be avoided. Lubricate only with clock oil. Cleanse working parts if necessary with benzene.

One of the most satisfactory polarizing microscopes is the Leitz\* No. 30, sometimes known as the Berkey Model No. 1, shown in Fig. 247.

The adjustable polarizer and analyzer are Glan-Thompson prisms and the condensing lens is inserted or thrown aside by rotating the milled head beneath the stage.

The stage is permanently centered. The graduation can be read to 1/10 of a degree. The upper plate is traversed by lines of orientation.

The graduated drawing tube has an inside diameter of 24 mm.

The Bertrand lens is of 6 mm. diameter, can be centered to the microscope, also focused with the draw-tube.

The Fuess microscope,† Model VI, Fig. 248, is planned to fit a large number of accessory devices and is especially characterized by the arrangement for simultaneous rotation of polarizer and cap analyzer, by the cogs  $rZ$ ,  $r'Z'$ , the object remaining at rest, but the same relative change taking place as if the stage were revolved and the nicols at rest.

There is an elaborate mechanical stage, the rotation of which can be read to minutes and has quick rotation by hand, slow rotation by ratchet, and sliding motions in two directions.

### **Preparation of Material for Optical Testing.**

As most observations are made by transmitted light it is necessary to prepare the objects so that they will transmit light and not overlap.

### **Sections in Crystallographic Directions.**

The tests unless otherwise specified require what is known as "plane parallel" plates, that is, that the light shall enter and

\* E. Leitz, Wetzlar, Germany, and N. Y.

† R. Fuess, Steglitz, Germany.

emerge from essentially parallel surfaces. Such parallel surfaces may be opposite faces of a crystal or cleavage, or a face may be cemented to glass and an opposite artificial face ground on or a section not parallel to any known face may be made at any angle and ground, and verified goniometrically with reference to other faces.

### **Rock Sections.**

A fragment may be chipped from the mass or a thin slice cut from it with an endless wire fed with carborundum or by a circular metal disc charged with diamond dust. One side is ground smooth and polished and cemented to glass and this ground down usually to a thickness of .03 to .04 mm. on a rotating disc fed with carborundum or emery.

After cleaning the thin fragment is cemented to glass by Canada balsam, and covered with a cover glass of .10 to .15 mm. thickness, using the same cement.

Good sections require\* very careful lapidary work and satisfactory tools and are to a great extent made by skilled workmen.

### **Crushed Fragments.**

In mineral testing much more rapid work can be done with the so-called "crushed fragment" sized by screens to an average thickness of .03 to .04 mm. The method of preparing suggested is as follows:

A small fragment is crushed by pressure in a small agate mortar (or by pounding on a steel plate with a hammer). Grinding is avoided. The crushed material is then sieved through a small 100-mesh screen† upon a 120-mesh screen, the finer portion penetrating that. The particles remaining on the 120-mesh screen are shaken out on a clean paper and a few fragments are placed on an object glass by a flattened wire or knife point. A drop of  $\alpha$  monobromnaphthalin or other liquid is placed to one side and the powder is drawn into it by a tilted cover slip which is then placed in position.

\* The process of preparation is described in detail in Chapter V of Luquer's "Minerals in Rock Sections," and in pp. 190-195, Iddings' "Rock Minerals" and other similar works.

† Easily made by boring a one inch hole through two square pieces of soft wood, say 2 in. x 2 in. x  $\frac{1}{4}$  in., inserting the wire gauze between and driving a pin-like brad near each corner.

$\alpha$  monobromnaphthalin has an index of refraction of about 1.655. It forms a plane parallel sheet between the object glass and cover glass, and eliminates the effects due to irregular surfaces of the enclosed particles more or less perfectly as its indices approximate or differ from those of the liquid.

### THE OPTICAL TESTS WITH THE POLARIZING MICROSCOPE.

**Determining Isotropic or Anisotropic.** (Singly refracting vs. Doubly refracting.) (See Depolarization, p. 111.)

With crossed nicols and (usually) white light and the condensing lens removed or lowered. Using moderate power, focus with upper nicol out, then push in the nicol and rotate the stage.

#### *Isotropic.*

If the field is dark throughout rotation the substance is singly refractive in this direction. If powder is being used the grain may be made to turn in the liquid by pressure with a point on the cover glass and other directions tried or a convergent light test may be made.

#### *Anisotropic.*

The field is dark at intervals of  $90^\circ$  and elsewhere illuminated, and often colored.

It is to be noted that "local" double refraction, varying in different places, may occur as a result of strain in singly refracting substances.

### DETERMINING INDICES OF REFRACTION.

While the methods of determining indices of refraction, p. 97, are essentially the same for all substances, it is only optically isotropic substances, p. 99, such as liquids, glasses and isometric crystals which with monochromatic light and constant temperature have each one index of refraction whatever direction of transmission is used.

In any doubly refracting substance the refractive indices vary with the direction of vibration of the light rays and if the problem is determining the *principal* indices of refraction certain definite directions of transmission must be secured. When this is not done the indices obtained are only intermediate indices.

Uniaxial crystals, p. 102, although singly refracting in one



direction, give two indices of refraction for any other direction of transmission; one of these is constant whatever the direction, the other varies between limits, the limiting values being the principal indices. Biaxial crystals, p. 105, have two directions of single refraction and two indices for each other direction of transmission and there is no constant index.

#### METHODS WITH LIQUIDS OF KNOWN INDICES.

In these methods involving a comparison with the known indices of liquids, a series of liquids which are transparent, stable and without action on instrument or substance are required. The number needed will depend upon the purpose, whether simply to classify in groups or to obtain as closely as possible the true indices.

Simple liquids or mixtures may be used. Johannsen gives a list of about seventy, ranging from water, 1.33, to molten selenium,\* 2.92.

Van der Kolk† particularly recommends about fifty, ranging from 1.33 to 1.93, and Wright,‡ from mixtures of a comparatively small number of liquids obtains any desired value between 1.45 and 1.96.

The liquids should be kept in small stoppered and capped bottles, preferably blackened and in systematic order. The determination of the index of any liquid at ordinary room temperature may be made quickly with a simple total refractometer, p. 133. If a piece of ground glass is placed on the drop of liquid the limit line of the liquid alone appears.

#### Determining the Index of Refraction by the Becke Line.

This test is based upon the occurrence of total reflection at a vertical boundary between two substances of different indices and a consequent concentration of light on the side of the substance with the higher index (denser substance).

In Fig. 251 let *BL* be the vertical boundary between the denser

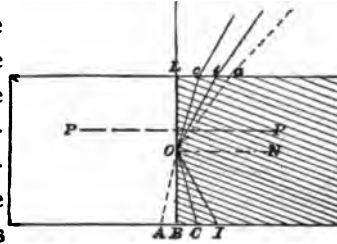
\* "Manual of Petrographic Methods," p. 260.

† "Tabellen zur mikroskopischen Bestimmung der Mineralien," von J. L. C. Schroeder van der Kolk, 2d ed., Wiesbaden, 1906.

‡ "Methods of Petrographic Microscopic Research," F. E. Wright, Carnegie Inst., 1911, p. 98. See also Merwin, *Jour. Wash. Acad. Sci.*, 3, 35.

(shaded) and less dense substances and let the microscope be focused at  $O$ . Then as explained, p. 98, all the oblique rays in the less dense medium incident at the contact plane will pass into the more dense, for instance,  $AO$  will continue as  $Oa$ , whereas of the rays in the denser medium all incident at the contact plane at more than the critical angle  $NOI$  will be totally reflected, for instance,  $CO$  will continue as  $Oc$ , and only the remaining rays pass into the less dense medium.

FIG. 251.



Evidently, therefore, if the light is narrowed by a light stop or iris or by lowering the polarizer, there will be a strong concentration of the light on the side of the denser medium.

On slightly raising the objective the focal plane, for instance  $PP$ , cuts the series of concentrated rays in a broadening band giving the effect of *a bright band moving into the denser substance*.

This test is made with a high power objective and a light stop below the stage upon a fragment or grain with an approximately vertical boundary or edge and surrounded by a liquid of known index.

If singly refracting any position of the fragment will give the same result, if doubly refracting the positions of extinction will give the greatest and least values.

With both nicols in, the stage is revolved until the grain is black. The upper nicol is then drawn out, the condensing lens and lower nicol lowered or a light stop used to prevent the entrance of divergent rays, and the microscope sharply focused on the vertical boundary. If the objective is now raised slightly, a line of light, parallel to the boundary, will appear to *move into the substance which has the higher index*. By lowering the objective the white line is moved in the opposite direction.

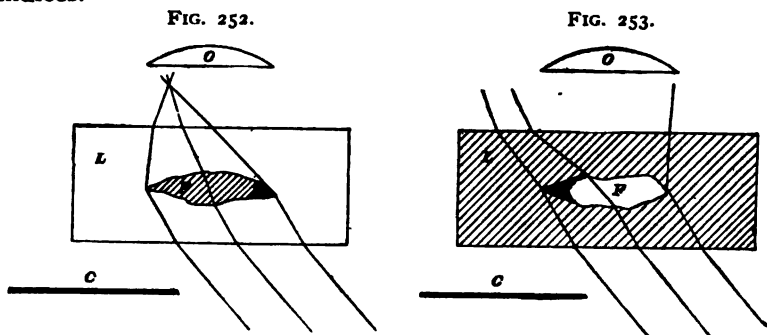
The method will detect differences of .001, therefore with a sufficient number of liquids will determine the true indices to this degree of accuracy.

#### Indices of Refraction by Oblique Illumination.

*Van der Kolk Test.*—If any fragment with tapering edges is immersed in a liquid it will act like a lens, and either concentrate

or disperse the light as the surrounding liquid is of lower or higher index.

When viewed with ordinary central illumination the effect in either case is a dark border, indicating merely a difference in indices.



If, however, by tipping the mirror, or, better, using the condenser and interposing a card or other obstruction to the light rays on one side the illumination is made inclined, different effects will be obtained, as shown, Fig. 252, in which the fragment *F* is the denser and the bright side is towards the card *C* and Fig. 253, in which the liquid *L* has the higher index and the bright side of the fragment *F* is away from the card *C*. *O* is the objective.

To obtain the results\* stated hereafter this test requires a medium power objective and *condensing lens*.

With both nicols in, revolve the stage until the grain is dark. Then, with the upper nicol out and the grain in focus, slide a sharp-edged card below the lower nicol, drop the condenser until the edge of the card is sharply focused, *then drop a little further*. Move the card slowly toward the grain and notice *which side of the grain becomes the brighter*.

Bright side of grain toward card—Index grain greater than index liquid.

Bright side of grain away from card—Index grain less than index liquid.

If the index of the grain is just that of the liquid for yellow

\* As explained by Wright, *Am. Jour. Sci.*, 21, 362, 1906, these phenomena can be reversed by raising or lowering the condenser. For the position of the card chosen (below the focus of the condenser) the results appear as stated below.

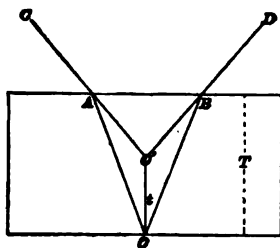
light, the grain will be bordered by red on the side near the card and blue on the opposite side.

#### METHODS AVAILABLE WITH GREATER THICKNESSES.

##### Duc de Chaulnes Method.

This method depends on the fact that if an image  $O$ , Fig. 254, is accurately focused and then a transparent plane parallel plate interposed between it and the objective the image is blurred and only becomes clear again when the objective is raised a distance  $OO'$ . The rays  $OA$  and  $OB$  are refracted on emergence and  $O$  appears to be at  $O'$ .

FIG. 254.



It may be shown\* that the displacement  $OO'$  or  $t$  is a function of the thickness  $T$  and the index of refraction of the substance.

The particular applicability of the method is for cut stones and crystals of high indices. It requires opposite parallel faces.† The manipulation is as follows: Set the fine adjustment screw of the microscope near the upper part of its motion, and place a minute spot of ink on the object glass. Center this spot, cover it with the crystal plate and focus upon the ink spot through the plate as sharply as possible. Remove the plate without disturbing the object glass; then, using the fine adjustment only, and keeping count of the number of rotations, lower the objective until the spot of ink is again in focus. Measure the thickness of the plate with a micrometer gauge and denote this thickness by  $T$ , and the displacement or change in focal length by  $t$ .

$$n = \frac{T}{T - t}.$$

##### Simple Refractometers.

Refractometers based upon the principle of total reflection, in which the indices of refraction can be rapidly determined upon polished or natural surfaces from a millimeter in diameter up are

\* If one good face exists a second parallel may be imitated by a drop of liquid and a bit of cover glass.

† Iddings, "Rock Minerals," p. 120.

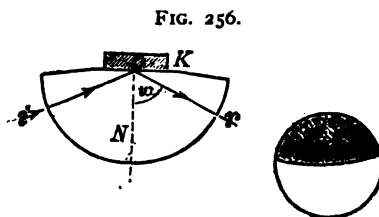
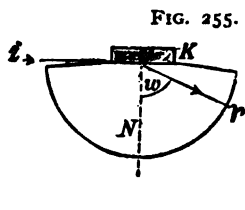
now considerably used in testing gems and could well be used more in determining minerals.

The surface of contact is the diametral plane of a glass hemisphere of very high index of refraction.

There are two methods of admitting the diffused incident light:

1. *From above the plane of contact.* The method of grazing incidence, Fig. 255, all incident rays bent towards the normal, the last ray  $iO$  to enter being that parallel to the contact plane, which emerges along  $Or$ , hence the field of a telescope in the direction  $rO$  would only have its lower half illuminated or allowing for the lens it would appear as shown.

2. *From below the plane of contact.* The method of total reflection proper, Fig. 256, all rays incident at more than the critical



angle  $Noi$  are totally reflected while those incident at smaller angles are largely transmitted through the crystal. The field of a telescope in the direction  $rO$  therefore receives more light in the upper half than in the lower and, allowing for the lens, it appears as shown.

Obviously light admitted both above and below produce counter-acting effects.

The manipulation is as follows:

Place a drop of liquid of known index of refraction on the center of the glass of the instrument; on this place the crystal face. Admit light from below or from above *but not both*, as counter-acting effects are obtained, and use the sodium flame. If only the limit line for the liquid is found, repeat with a liquid of higher index of refraction.

Carefully revolve the crystal, keeping the same face in contact with the glass. If the revolution produces no movement in the

limit line or lines, the value is read and the note made that the substance is probably either amorphous or isometric. If the revolution produces obvious movement, and two lines are obtained, both are read *when at their greatest distance apart*. It should be noted whether one (uniaxial) or both lines (biaxial) move during the revolution.

In the simpler instruments such as the Fuess Simple Refractometer Model 4, shown in Fig. 257, in section, 1/2 scale, or the Herbert Smith refractometer shown in outline; full scale, in Fig. 258, the resulting sharply divided light and shade are viewed through the eye piece on a scale *S*, Fig. 257.

FIG. 257.

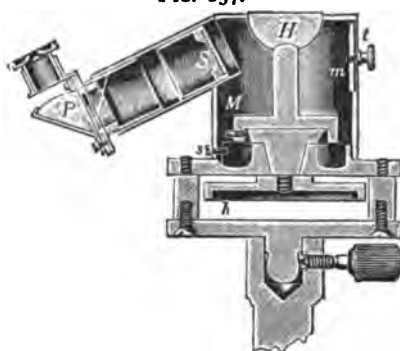
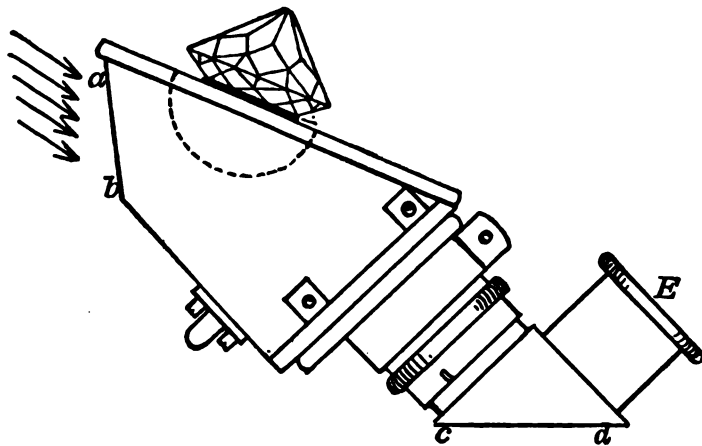


FIG. 258.



The glass of the hemisphere in both instruments has an index of refraction a little over 1.8. The scales read to 1.8. Fig. 259 shows the appearance of the scale with a singly refracting substance of index 1.49, Fig. 260 shows the scale with a doubly refracting substance with indices 1.66 and 1.70.

FIG. 259.

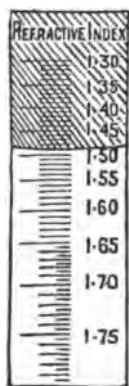
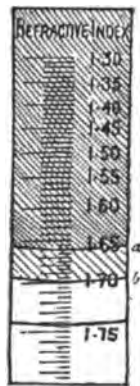


FIG. 260.



### Determining the Sign of Elongation.

The direction in which a crystal or a crystal section is longest is called its elongation (or sometimes its principal zone). This direction in uniaxial crystals is often the direction of the axis  $c$  and in the needles, fibers, etc., obtained by crushing it is connected with the structure, especially the cleavage.

If the elongation is parallel or approximately parallel to one of the vibration (extinction) directions of the fragment or section a useful subdivision results by determining whether this vibration direction corresponds to the *faster* or to the *slower ray*.

The vibration (extinction) directions in the section are found and the stage is revolved  $45^\circ$  from that extinction position which is nearest the "*elongation*" and the interference color is noted.

A test plate of known retardation  $\Delta$  and on which the directions\* of vibration  $X$  and  $Z$  (or  $a$  and  $c$ ) of its fastest and slowest rays are marked is then inserted in the slot above the ocular. The changes in color and the moving in or out of the color bands along the periphery of the section or fragments are noted.

If the new color on comparison with the color chart is higher by  $\Delta$  of the test plate and the color bands move *out*, then corresponding vibration directions of substance and the test plate are parallel if, on the contrary, the new color is lower by  $\Delta$  and the color bands move *in* the corresponding vibration directions are crossed.

\* Strictly  $X$  and  $Z$  are the principal vibration directions of the crystal.

The directions of  $X$  and  $Z$  therefore being now known the following convention exists.

The sign of elongation is plus (+) when the elongation is parallel  $Z$ , and minus (−) when the elongation is parallel  $X$ .

The test plate most used is the *Quarter Undulation Mica Plate*, a sheet of mica of thickness corresponding to a blue gray interference color or say  $140\ \mu\mu$  which is  $1/4\lambda$  for a medium inter-yellow.

A very gradual tapering wedge is even better as the succession of colors prevents mistake.

The slot above the objective may be parallel to a cross hair in which case the vibration directions of the test plate must be diagonal, or the slot may be diagonally placed and the test plate made with its length parallel  $X$  or  $Y$ .

The former method is more convenient as the simple turning of the test plate upside down reverses its relation to the crystal under examination.

#### DETERMINING BIREFRINGENCE.

The birefringence or strength of double refraction of any doubly refracting substance is the difference between its maximum and minimum indices of refraction. If these indices can be determined to the third decimal their difference may be taken as the birefringence.

In practice the birefringence is usually determined from the retardation and consequent interference color and the thickness of the section. This gives the true birefringence of the substance only in exceptional cases.\*

The relation between retardation  $\Delta$ , thickness  $t$  and refractive indices  $n_1$  and  $n$  for any section are:

$$\Delta = t(n_1 - n).$$

The retardation and the thickness must of course be expressed in the same unit.

The retardation can be measured with considerable accuracy by compensators. The thickness determination is less accurate.

\* In uniaxial crystals only when the section is parallel the optic axis and in biaxial crystals only when the section is parallel to the plane of the optic axis.



### Determining the Retardation by a Compensating Wedge.

The process is closely that for determining the sign of elongation.

The section or grain is focused, the upper nicol pushed in, an extinction position is found, and the stage revolved  $45^\circ$  to the position of brightest illumination. The interference color is carefully observed and then a wedge of some mineral is inserted in the slot above the objective and the interference color of the combination noticed, if this is higher than before the conditions are reversed so that the corresponding vibration directions are crossed and the wedge gradually pushed in until the interference color is run down to black.\*

The value of  $\Delta$  for the thickness of wedge interposed is the desired value and this may be approximated by counting the number of times during the insertion of the wedge the original color reappears, if  $n$  times, then the color is a red, blue, green, etc., of the  $n + 1$  order, for which the value may be looked up in a color chart.

If at the position of compensation the *mineral* is removed the color given by the wedge alone should be that shown by the mineral alone and the wedge may be gradually withdrawn and the color repetition used as a check.

The wedges most used are:

*The Quartz Wedge.*—A thin wedge-shaped plate of quartz mounted between glasses and usually showing four orders. The values of  $\Delta$  for different places may be shown on a scale.

*The von Federow Mica Wedge.*—Composed of fifteen quarter undulation mica plates superposed in equivalent position, but each about 2 mm. shorter than the one beneath it. Each plate compensates by  $140 \mu\mu$ . If  $n$  plates are needed to render the field dark then\*  $\Delta = n \times 140$ .

Many more elaborate compensators exist such as the Babinet compensator, the Michel Levy comparator, the Wright combination wedge, with which  $\Delta$  may be determined within a few  $\mu\mu$ . Usually they cannot be attached to the simple microscope.

Bands of interference colors on wedge-shaped outer portions of fragments may be counted, giving thus approximately the color order.

\* Weinschenk recommends running down to sensitive violet No. 1,  $\Delta = 575 \mu\mu$ . This value would then be added to the value of  $\Delta$  interposed.

† That is, if one step is dark and the two adjacent steps equally bright,  $\Delta = n \times 140$ , but if no step is dark and two adjacent are equally bright the value is intermediate.

Very low values of  $\Delta$  (low order whites, grays, etc.) may be approximately determined by use of test plates, giving the sensitive violet No. 1,  $\Delta = 575$  such as:

*The Gypsum test plate.*—A value as small as  $10\mu$  added or subtracted notably changes the color.

*The Bravais double plate*, consisting of two halves of a sensitive violet set in opposite direction, is even more delicate. Originally made of mica  $\frac{1}{4}$  mm. thick. It is said to react for the double refraction produced by finger pressure on a cube of glass.

### Measuring the Thickness of the Crystal or Fragment.

If the refractive index of the substance is known the simplest plan is to focus successively on its upper and lower surface, using the fine adjustment screw. The distance corresponding to the movement of the screw multiplied by the average index of refraction of the substance is the thickness.\* This is the de Chaulnes method, p. 131.

If the section is loose a mark may be made on an object glass and focused, then the section slid on and the fine adjustment turned until some point on the surface is in focus. This is independent of the index of refraction.

The error diminishes with increasing thickness; with thin sections it will probably be ten per cent.

### Determining the "Birefringence."

The quotient obtained by dividing the retardation by the thickness  $t$  is the strength of the double refraction of *that section*. It is only that of the crystal when the section, as before stated, is parallel to the optic axis (uniaxial) or plane of the optic axes (biaxial).

### Approximate Determinations of Birefringence in Terms of Color.

It is sometimes convenient to classify fragments or sections of approximately constant thickness by their birefringence expressed in terms of color. For instance, for crushed fragments or sections five color terms can easily be used. The terms of color, and the equivalent birefringences for a thickness 0.035 mm., and the detail, or effect, of the test-plates may be stated as follows:

\* If small basal cleavages of barite are placed at the corners of the slide and ground down with it, their interference colors can be used to determine the thickness for  $n_1 - n = .01$ , hence  $t = \Delta/.01 = 100\Delta$ .

| Term of color.    | Detail.   | Equivalent Birefringence. |
|-------------------|---|---------------------------|
| BLACK.....        | Unchanged by rotation.....  | 0                         |
| GRAY OR WHITE ... | By gypsum plate made yellow for crossed position, blue or purple for parallel position.....                                     | < 0.008                   |
| BRIGHT A.....     | By gypsum plate made white or gray or black for crossed position.....   | 0.008 to 0.024            |
| BRIGHT B.....     | By gypsum plate bright colors for both positions. By mica plate notably different tints for crossed and parallel positions..... | 0.024 to 0.06             |
| HIGH ORDER.....   | Not describably affected by mica plate in either position.....  | > 0.06                    |

The term "Bright" signifies definite, brilliant colors. "High order" signifies faint varied tints not easily distinguished, and grading into white. Bright A are the lower-order bright colors reducible to whites, etc., by the gypsum plate.

#### Abnormal Interference Colors.

Strictly the birefringence of a doubly refracting substance, while often more constant than the indices of refraction, is not the same for all colors.

In some minerals it is zero for certain wave-lengths. If, as with vesuvianite and chlorite, for instance, it is near zero for yellow, a deep blue appears no matter what the thickness of the slide. Other minerals show other abnormal colors.

The color of the mineral itself may modify the interference color and in some monoclinic or triclinic crystals a modification results because the colors have no constant positions of darkness.

#### DETERMINING EXTINCTION ANGLES BETWEEN CROSSED NICOLS.

As explained, p. 111, when either of the two rays emerging from a crystal section is parallel to the vibration direction of the lower nicol the field is dark.

The angle between this direction and some recognizable crystalline direction, cleavage, crack, face, twin plane, etc., is called the extinction angle of the section.

#### General Method.

Place the section on the stage of the microscope, focus with the upper nicol out, make some characteristic crystalline direction

coincide with a cross hair, read the vernier, push in the upper nicol and rotate the stage of the microscope until the field is at its maximum darkness. Again read the vernier. The difference between the two readings is the extinction angle of the section with the chosen direction.

Because of the gradual change from light to darkness the recognition of maximum darkness is difficult and if a closer determination is desired, the average of a number of measurements taken as follows may be used.

After carefully determining the position of the crystalline direction rotate the stage clockwise until the field is dark at some reading  $a$ . Continue the rotation until the field is light, then turn back counter clockwise to some reading  $a'$ . The reading halfway between is near maximum darkness.

With *colorless crystals* the determination may be verified by slightly rotating the upper nicol. If the installation is accurate the field and the crystal will brighten simultaneously, retaining the same tone.

#### **Sensitive Tint Plates.**

If the gypsum test plate, p. 137, or a quartz plate yielding sensitive violet No. 1 is inserted in the slot above the objective and the grain or section adjusted to only partly cover the field, the entire field will be violet for the extinction positions but the slightest rotation will change the color of the mineral to purple or indigo.

The Bravais double plate, p. 137, will do this with even greater delicacy one half becoming purple, the other indigo.

Many other devices exist also involving color contrasts developed when the vibration directions of the fragment and the nicols are nearly but not quite parallel.

To all of these are two strong objections.

1. They are not available for monochromatic light.
2. They transmit only a small percentage of the light and are effective only for crystal sections which are light in color and which themselves yield the low colors of the first order.

#### **Special Points Extinction.**

In tetragonal, hexagonal and orthorhombic crystals, the vibration directions coincide with the crystal axes for light of any wave-

length. Hence white light is used and *in general* the extinction direction will be *parallel* or *symmetrical* to observed crystalline directions.

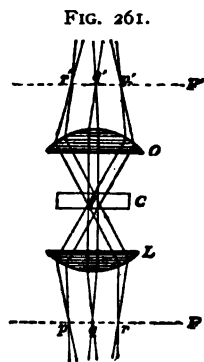
In monoclinic crystals the maximum and characterizing extinction angles are obtained in sections parallel to the plane of symmetry.\* Moreover, because the vibration directions are different for light of different wave-length monochromatic light should be used.

#### DETERMINING UNIAXIAL OR BIAxIAL BY INTERFERENCE FIGURES.

The optical properties of a crystal may be studied, not only in one direction but simultaneously in a great number of different directions, by use of convergent polarized light.

With the polarizing microscope select by parallel light a suitable grain or section, either one that shows darkness between crossed nicols for a complete rotation or one that retains a uniform illumination throughout or failing these a grain which for a given thickness shows the lowest interference color (that is, is nearest normal to an optic axis).

This grain is then carefully focused, using a high power objective and the condensing lens directly under the stage. The upper nicol is pushed in, *the eye piece* removed, and the interference figure viewed by looking down the tube.



The interference figure thus seen is made by the objective alone, these images are small but often sharply defined, the removal of the eye piece, however, makes it impossible to measure the distance between the axial points in any biaxial figure. A magnified image† can be obtained if the eye piece is retained and the Bertrand lens inserted in the microscope tube as described, p. 123.

What has happened may be briefly explained as follows:

In Fig. 261 the foci of the objective *O* and

\* This plane being always parallel or perpendicular to the plane of the optic axes can be found by convergent light tests.

† The image can also be seen through the eye piece by means of a hand glass held a little above it.

the condensing lens  $L$  coincide at  $f$ . Every point,  $p$ ,  $q$  or  $r$ , in the focal plane  $F$  is the vertex of a cone of rays which is made parallel by  $L$ , traverses the crystal as a parallel bundle and is by  $O'$  again brought to focus at points  $p'q'r'$  of the focal plane  $F'$ . Each direction in the crystal plate therefore is traversed by a minute bundle of parallel rays, which undergo the same extinction and interference phenomena as were described for parallel light, and record them at some point in the focal plane  $F'$ .

Every point of the image formed in the focal plane  $F'$  therefore corresponds to a direction in the crystal and is dark four times in a revolution and of a specific color at all other times. The image is known as the "*interference figure*," the shape, brightness and tints of which depend upon the structure of the plate for *all the directions* traversed by the rays.

The results obtained differ as the crystal is isotropic, uniaxial or biaxial.

*Isotropic*.—The section which remained dark throughout rotation in parallel polarized light between crossed nicols still remains dark.

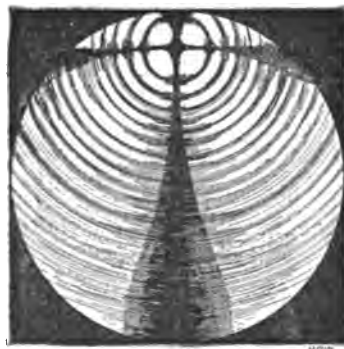
#### UNIAXIAL INTERFERENCE FIGURES.

The section which remained dark throughout rotation in parallel polarized light between crossed nicols is at right angles to the

FIG. 262.



FIG. 263.



optic axis. It does not remain dark in convergent light but develops the characteristic interference figure, Fig. 262, which consists of

1. A dark cross, the arms of which intersect in the center of the field, and remain parallel to the vibration directions of the nicols during rotation of the fragments.

This cross, sometimes called the isogyres, corresponds to the emerging rays which for any one position of the stage have their vibration planes parallel to the nicols. As the stage is rotated successive rays come into these positions, maintaining the same effect.

2. With monochromatic light the field will be of the color used, but if the section is not too thin,\* the center of the black cross will be surrounded by concentric dark circles.

Suppose a cone of polarized monochromatic light passed through the plate with its axis, parallel to the optic axis. The ray in the direction of the axis will pass through unchanged and be stopped by the analyzer. All oblique rays at some particular angle will have a phase difference equal one wave-length and therefore will yield a circle of darkness. The rays at some larger angle will have a phase difference equal two wave-lengths and yield a second concentric circle of darkness and so on.

With white light the concentric circles will be color rings, arranged strictly in the order of the interference colors.

#### **Oblique Sections.**

From sections which in parallel light were not black but showed the lowest obtainable interference color, an eccentric interference figure may be obtained, Fig. 263. The center of the figure revolves as the stage is rotated but the arms of the black cross remain parallel to the vibration planes of the nicols, unless the obliquity is great when they may be curved.

#### **If the Birefringence is Weak.**

There may appear only the black cross and no rings which may be so hazy that the existence of a figure is best proved by using the gypsum test plate in which case two opposite quadrants will be colored blue and two orange.

\* In uniaxial crystals in which the optic axis is a direction of circular polarization the interference figures from thin sections are essentially as described but in thicker sections the bars do not reach the center and the inner circle has that color tint which the entire section would have with parallel light. On turning the analyzer this color will change in an order dependent on the direction of rotation produced by the substance.

## BIAXIAL INTERFERENCE FIGURES.

## Sections Perpendicular to Acute Bisectrix.\*

When obtainable a section equally inclined to both optic axes, that is, normal to the *acute bisectrix* yields the following very characteristic figure:

1. Whatever the position of the plate the "isogyres" appear as two dark bars or brushes which correspond to the emergence of rays with their vibration planes parallel to those of the nicols. They are not constant in shape. For the so-called normal position one connects the points of emergence of the optic axes, the other is a thicker, lighter band at right angles to the first and midway between the axes.

FIG. 264.

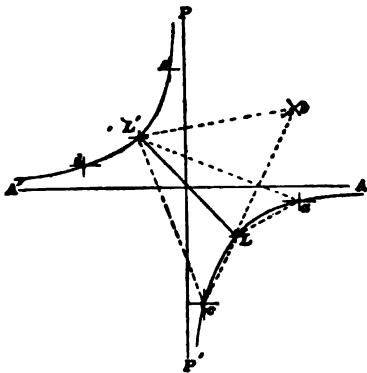
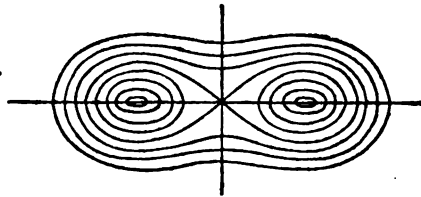


FIG. 265.



If the stage is rotated, other rays vibrate parallel to the nicols and the straight dark lines seem to dissolve into an hyperbola the poles of which are the loci of the optic axes and, Fig. 266, the branches of which rotate in the opposite direction to the rotation of the stage. The convex side of each is always toward the other branch.

The Isogyres can always be graphically found as follows:

The directions of vibration of any pair of emerging rays can be found by bisecting the angles between the two lines formed by connecting the point with the loci of the optic axis.

The isogyres result by connecting those points, the vibrations at which are parallel to the vibrations of the nicols.

\* To determine the acute bisectrix it may be necessary to first measure the axial angle. Ordinarily the interference figure in a section normal to the obtuse bisectrix will resemble the figure parallel to plane of optic axes, Fig. 267, and the axial loci will not be visible.



1. A dark cross in the field, and reappears when the nicols during rotation.

This cross, composed of emerging rays, is seen in the vibration plane. Successive rays

2. With the light but if the plate will be seen.

Suppose the plate is in the direction of vibration by the light. We have

yield

have

second

When

are

O

the emergence of the optic axes.  $PP'$  and  $AA'$  analyzer respectively, then the rays connecting any point as  $a$ ,  $a'$  will be on  $AA'$  whereas for other points they will be in these directions. The sectors nearly parallel  $PP'$  and  $AA'$  will be seen resulting in a broad brush rather

When monochromatic light there will be, in a field, curved curves around the loci of the axes. Retardations of one, two, three, etc., orders will not be circles but ovals which will come until some pair unite at or near the center in a figure eight around both axes and form anniscates around this as in Fig. 265. These do not change on rotation of the plate.

FIG. 267.



When is used the superimposed interference figures may be more complex as neither the axial loci nor the isogyres or curves of equal retardation coincide, and upon the changes in the chromatic curves during the rotation rest important differences between crystalline systems.

### When Perpendicular to an Optic Axis.

Sectors which remain uniformly illuminated with parallel light between crossed nicols are at right angles to an optic axis and yield an interference figure somewhat like the cross figure. The black cross, however, is replaced by a single

black bar, essentially straight, Fig. 268, whenever the trace of the plane of the optic axes coincides with the vibration direction of other nicols. For all other angles of rotation it is curved and resembles one arm of an hyperbola through the axis, Fig. 269, the convex side toward the other axis. This arm rotates in the opposite direction to the rotation of the stage.

FIG. 268.

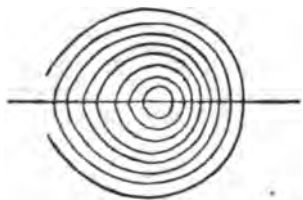


FIG. 269.



### Oblique Sections.

The sections which in parallel light between crossed nicols yield the lowest interference colors show figures something like those just described. The single black bar which rotates in the opposite direction to the stage proves the biaxial character.

### Sections Parallel to the Plane of the Optic Axes.

Such sections yield in monochromatic light an interference figure, Fig. 267, not easily distinguishable from that given by a uniaxial plate cut parallel to the optic axis.

### DETERMINING THE CHARACTER OF THE DOUBLE REFRACTION.

#### Optical Character of Uniaxial Crystals in Parallel Light.

If the direction of the optic axis is known from the shape of the crystal or otherwise, the ray vibrating parallel to it is the extraordinary. Or if determinations on several fragments yield one constant index of refraction (ordinary) and one varying (extraordinary), then the character results by

(+). The ordinary or constant index is less than the extraordinary or varying index.

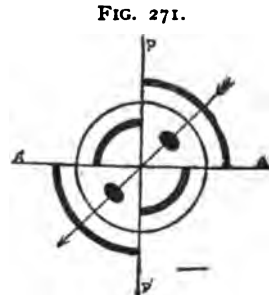
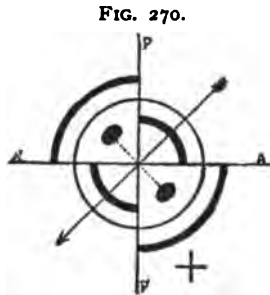
(-). The constant index is greater than the varying index.

No corresponding test exists for biaxial crystals.

### Uniaxial Crystals with Convergent Light.

The interference figure, Fig. 262, is changed characteristically by test plates inserted in the slot above the objective.

The *Quarter Undulation Mica Plate* inserted with its vibration directions diagonal to those of the nicols breaks the color rings into quadrants, and breaks the cross at the center developing two



black spots. The relative effects in positive and negative crystals are shown in Figs. 270, 271, the arrow being the vibration direction  $Z$  of the slower ray of the mica plate. The corresponding signs  $+$  and  $-$  are suggested by the relative position of these dark spots and the direction  $Z$ .

If the *Gypsum Test Plate* is similarly inserted the black cross becomes reddish violet and near the center two opposite quadrants become blue, the other two yellow.

If a line be assumed to join the blue quadrants this line in positive crystals crosses the direction of vibration  $X$  and in negative crystals is parallel to it, again suggesting the corresponding  $+$  and  $-$  signs.

### Uniaxial Oblique Sections.

Rotate the plate until only one quadrant of the figure is in the field, judge the position of the center of the cross by the arms or curvature of the color rings, insert the mica and note the position of the shifting color arcs or of any developed dark spot with reference to  $Z$  of the mica plate.

### Biaxial Sections Normal Acute Bisectrix.

In sections normal the acute bisectrix, the *quarter undulation mica plate* may be used as described above, for uniaxial crystals

when the distance between the points of emergence of the axes is small.

The compensating quartz wedge may be inserted successively with  $Z$  and  $X$  parallel to the diagonal line connecting the axial points. In one of these insertions the rings around each axis will *expand*, moving toward the center and corresponding rings will merge in one curve. When this direction is  $Z$  the character is plus (+), when the direction is  $X$  the character is minus (-).

### Biaxial Sections Showing the Optic Axis.

Sections perpendicular, or nearly, to an optic axis show the dark bar which is noticeably convex\* towards the acute bisectrix. If rotated into the position of Fig. 269 and the gypsum test plate inserted <sup>with  $X$  parallel to trace of plane of optic axes</sup> the bar becomes violet red but is differently bordered in positive and negative crystals.

Positive crystals concave side yellow, convex side blue.

Negative crystals, concave side blue, convex side yellow.

### Determining the Angle between the Optic Axis.

As stated p. 105 the so-called optic axes of biaxial crystals are determinable directions for monochromatic light and constant temperature. The angle between them can therefore be measured.\*

The optic axes lie in the plane of  $X$  and  $Z$  and these directions bisect the angles between the axes. Either however may be the acute bisectrix  $Bx_a$ , Fig. 272.

Usually a plane parallel plate is cut normal to the acute\*bisectrix.

The rays travelling parallel to the optic axis are obliquely incident at the air and are refracted, the apparent angle, Fig. 272, denoted by  $2E$ , being larger than the true angle, denoted by  $2V$ .†

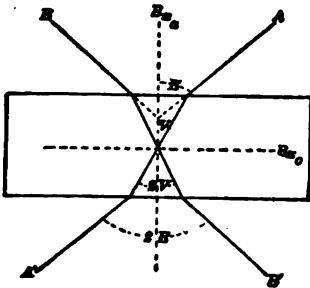
Although‡ a definite character for a crystal of definite com-

\* Unless the axial angle is very close to  $90^\circ$ .

† In Fig. 272, for instance,  $2V = 56^\circ$ ,  $2E = 98^\circ$ .

‡ In orthorhombic crystals the same plate will be normal for all colors, but in the other systems this is not so, but if the plate be cut normal for a middle color, say yellow, the results for all colors will be approximately accurate.

FIG. 272.

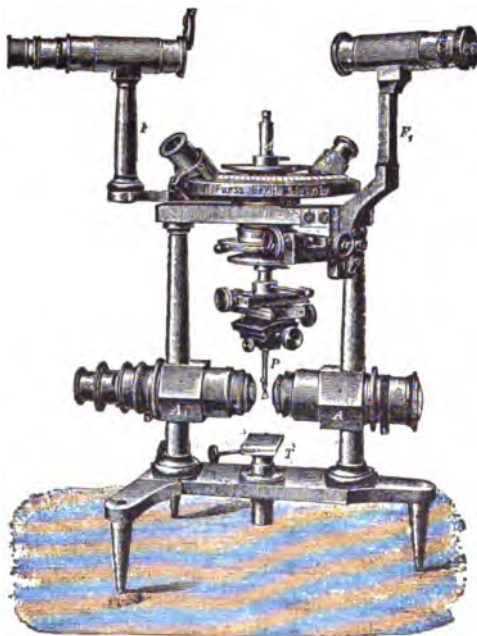


position  $2V$  varies widely in the great minerals which are isomorphous mixtures and is therefore less used than the other optical characters.

#### Determining the Apparent Angle with the Microscope.

The apparent axial angle\*  $2E$  may be determined in such a plate as Fig. 272 in any suitably equipped microscope, by measuring the distance,  $2d$ , between the points of emergence of the optic axes. Usually the interference figure is placed in its diagonal position, Fig. 266, and the distance  $2d$  measured between the foci of the hyperbola by some form of micrometer eye piece.

FIG. 273.



Then  $\sin E = d/C$ , in which  $C$  is a constant for the same system of lenses and is determined once for all by means of crystals of known axial angles.

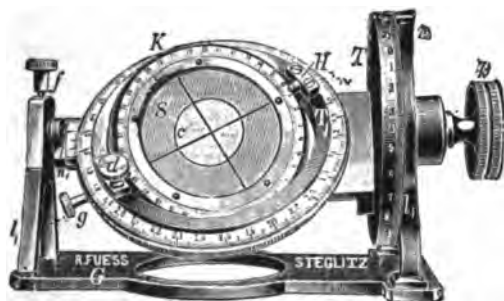
\* The axial angle can also be determined in sections showing the emergence of only one optic axis by means of the curvature of the isogyres (p. 143). (See Johanssen, "Petrographic Methods," p. 480.)

For instance, if in a mica  $2E = 91^\circ 50'$  and  $d = 41.5$  divisions on the scale, then  $C = d/\sin E = 57.78$  for that combination of lenses.

#### Determination of the Axial Angle by Rotation.

A more exact measurement may be made by actual rotation of the plate about  $Y$  as an axis. The microscope, with some form of rotation apparatus, Fig. 274, attached, may be used or a polariscope, Fig. 273. The microscope or polariscope is usually

FIG. 274.



v. Federow Universal Stage.

horizontal and the nicols are crossed at  $45^\circ$  to the horizon, so that when the line connecting the axial points is horizontal the interference figure shows the hyperbola. The section is adjusted so that the axial points of the interference figure remain on the horizontal cross hair during revolution.

The crystal is then revolved and the arms of the hyperbola are successively made tangent to the vertical cross hair. The difference between the two readings is the apparent angle  $2E$ .

#### Determining the True Angle.

A second measurement may be made of the apparent angle in a plate normal to the obtuse bisectrix. Denoting this by  $2E'$  the relation is  $\tan V = \frac{\sin E}{\sin E'}$ .

If the middle index  $\beta$  is known

$$\sin V = \frac{\sin E}{\beta}$$

If the section is immersed in a liquid of index or even the mean index found by Becke test, then  $E = V$ .

**DETERMINING THE CRYSTALLINE SYSTEM BY OPTICAL TESTS.**

The crystalline system can usually be identified as follows:

If each grain or section tested is *Homogeneous*, that is, shows in all parts the same optical behavior. Determine by test page 127 whether isotropic or anisotropic.

*A. Isotropic.*—Confirm by the fact that no interference figure is produced by convergent light.

(a) *Amorphous.*—Absence of crystalline form or cleavage.

(b) *Isometric.*—Presence of crystalline form or cleavage.

*B. Anisotropic.*—By test page 140 seek out suitable fragment or section\* and determine whether uniaxial or biaxial.

(a) *Uniaxial.*—Confirm by fact that in other grains or sections extinction always takes place for directions parallel or symmetrical to crystal outlines, cleavage cracks, etc., p. 139.

No purely "optical" distinction exists between the tetragonal and hexagonal crystals. The section or fragment which yielded the interference figure may show outlines or cleavages characteristic of the system.

Tetragonal—Angles of  $90^\circ$  or  $135^\circ$ .

Hexagonal—Angles of  $60^\circ$  or  $120^\circ$ .

(b) *Biaxial.* 1. *Orthorhombic.*—In the interference figure obtained in grain or section normal to a bisectrix *with white light* the shape of the isochromatic curves will be symmetrical to the line joining the optic axes, to the line through the center at right angles thereto and to the central point.

In all sections or grains parallel to any one of the three crystallographic axes  $\bar{a}$ ,  $\bar{b}$ , and  $\bar{c}$ , the extinction will take place with parallel light in directions parallel or symmetrical to cleavage cracks and crystal outlines.

There may be two cases dependent on the different axial angles for light of different wave-length, and as the colors fringing the hyperbola will be in inverse position to the axial

\* Much can be done with forms of rotation apparatus. Fig. 274 shows the v. Federow Universal Stage with three axes of rotation. The stand *ll'* carrying the stage can be placed on the stage of the microscope. By *k* the stage is rotated about a horizontal axis, the amount of rotation being shown on *T*. The stage *K* is rotated about a second axis perpendicular to the first, the amount being read on the vernier *n*<sub>1</sub>; it also carries a third axis, *Hd* (a diameter in its plane). Finally the glass plate, *S*, carrying the object can be rotated in its plane.

points. For red less than violet, the red is further from the center than the blue. For red greater than violet, the red is nearer the center than the blue.

2. *Monoclinic*.—In the interference figure obtained described above with white light the shape of the isochromatic curves will be symmetrical to *one* line or the central point. The line of symmetry may join the axial points (Inclined Dispersion) or (*b*) be at right angles to this (Horizontal Dispersion) or there may be symmetry to the center (Crossed Dispersion).

In all grains or sections parallel to the axes of geometric symmetry *extinction* will take place in directions parallel or symmetrical to crystal outline or cleavage cracks.

In all other grains or sections the directions will be oblique and unsymmetrical.

(*c*) *Triclinic*.—In the interference figure with white light the isochromatic curves are not symmetrical to line or center.

The directions in which extinction takes place are always oblique and unsymmetrical to crystal outlines or cleavages.

#### ABSORPTION, COLOR AND PLEOCHROISM.

##### Absorption.

When monochromatic light is either reflected from or transmitted through a crystal it undergoes partial absorption, the amount absorbed increasing with the thickness.

If the crystal is doubly refracting the rate of absorption will probably be different for the two rays transmitted in any direction and also different in different directions.

If white light, composed of a multitude of lights of different color and different wave-lengths, is used each component light is affected as described, but the percentages absorbed may be either alike or different (Selective Absorption).

##### Color.

If the absorption of all the colors has been essentially in the same ratio the body appears colorless or white. If not in the same ratio, then it appears that tint which results from the combined effect of the unabsorbed portions of the component lights.



The color depends also on the proportions\* of the different monochromatic colors in the light used as a source, for instance, alexandrite is red by candle light, green by sunlight and of an intermediate tint by a tungsten light. The substance simply possesses the power to absorb certain tints, that is, light of certain wave-lengths more rapidly than others. The "color" is what is left.

#### **Transparency vs. Opacity.**

If the non-absorbed rays penetrate the substance it appears transparent and colored or colorless, if they are all reflected it appears opaque, colored or white. If all are absorbed it appears black.

#### **Pleochroism in General.**

In doubly refracting crystals the color in different directions may be noticeably different as in epidote and iolite.

The two rays transmitted in any one direction may also be differently colored. Usually the eye observes a mixed resultant color.

This variation in color is called pleochroism or dichroism. It is impossible in singly refracting material and in colorless doubly refracting material. In colored doubly refracting material it is a common but not necessary phenomenon, and when present is best displayed by the deeper colored crystals.

#### **Pleochroism in Uniaxial Crystals.**

The optic axis is a direction of single refraction for white light and pleochroism does not occur in this direction, that is, *in sections normal to the optic axis* the color is constant, but in any other section the two rays are differently absorbed and may be differently colored.

The color of one of these rays is constant for a given thickness whatever the direction of the section. The color of the other varies with the section and differs most from the constant (ordinary) ray in the section cut parallel to the optic axis and in all other sections the ordinary will be found to approach the constant

\* The proportions of the different monochromatic colors varies even in sunlight, and the differences between even the best artificial light and sunlight are very great, the former usually containing far greater proportions of yellow and red.

tint of the ordinary as the sections become more nearly perpendicular to the optic axis.

*The relation of absorption to transmission varies:* the directions of principal absorption (maximum and minimum) coincide for all colors with the principal vibration directions *X* and *Z*.

There is no necessary relation between degree of absorption and indices of refraction and two classes may be made.

1. Absorption of ordinary ray greater than that of extraordinary ray.
2. Absorption of ordinary ray less than that of extraordinary ray.

### **Pleochroism in Biaxial Crystals.**

A pleochroic biaxial crystal shows pleochroism in all directions.

It is true there are for any one temperature and light of any one wave-length two directions of single refraction. But when white light is used each color has its slightly different direction of single refraction and moreover the light which emerges travelling in one of these directions is merged with the doubly refracted light from an inner cone of rays which *after emergence* travel in the direction of the optic axis, therefore any such composite bundle will show dichroic effects and will not give darkness between crossed nicols.

It is customary to record the colors obtained for rays vibrating parallel *X*, *Y* and *Z* and where possible to record also the relative degrees of absorption in these directions.

The directions of principal absorption (maximum and minimum) coincide with *X*, *Y*, *Z* for all colors in orthorhombic crystals. They do not so coincide in triclinic crystals nor completely coincide in monoclinic crystals.

There is no relation between the degree of absorption and the indices of refraction. Maximum absorption may be in the plane of the optic axes or perpendicular thereto.

### **Determining Pleochroism with the Microscope.**

Minute grains and fragments as well as larger sections may be examined as follows: Focus with the upper nicol out; push in upper nicol and rotate the stage until the field is dark; push out the upper nicol and note the color of stone. Rotate the stage  $90^\circ$  and again note the color. These positions usually give the maximum difference in color for the direction of transmission. The pleochroism may appear as a change in color or a change in the shade of the same color.

In intermediate positions of rotation the color is due to components of each of the extreme colors, in the diagonal position these components are equal.

There emerge from the stone two rays vibrating at right angles but differently absorbed and possibly colored, but not sufficiently divergent to be seen separately and yield a combination color.

If one can be held back the other can be seen or *vice versa*. When the lower nicol of a microscope is parallel an extinction direction one of the two rays that gets through and its color is seen. When the stage has been revolved  $90^\circ$  the other ray gets through and its color is seen.

In intermediate positions the color is due to both.

If it is desired to show the colors side by side a dichroscopic ocular may be used, Fig. 275. The action is like that of the dichroscope described below. It is especially applicable to the grains in thin sections.

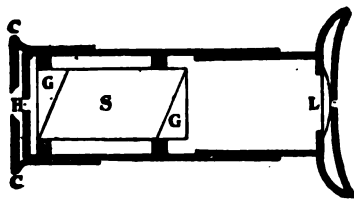
#### Determining Pleochroism with Dichroscope.

The colors of the ordinary and extraordinary rays may be contrasted side by side by means of a "dichroscope," Fig. 276, which

FIG. 275.



FIG. 276.



is in its essentials a cylindrical casing with a rectangular hole, *H*, at one end and a lens, *L*, at the other and between a rhomb of calcite *S* of such a length that the two images of the hole are *just* in contact.

In some instruments the terminal faces of the rhomb are ground at right angles to its length, but usually wedges of glass *G* are attached.

*The section or stone to be tested may be directly attached to a movable cap C by means of some kind of wax or cement so that the light which has traversed it passes into the window, H.*

The instrument shown, Fig. 277, has convenient devices by which the crystal, or section, or cut stone may be held and turned about two axes, one at right angles to the length of the tube, the

other parallel to the length of the tube, and thus examined in different directions.

FIG. 277.



*The method of using is as follows:* Hold the stone close to the square orifice and rotate the instrument until the two images are of the same color. Midway between two such positions the colors differ most. Whether pleochroism is shown for this position or not, place the stone in a second notably different position and again try for the limit colors.

In examining a cut stone revolve the *dichroscope* rather than the stone so as to avoid different light effects from different positions of facets, and verify the fact that the differences are due to pleochroism by noting that the two images of any face interchange colors for  $90^\circ$  of rotation of the dichroscope.

The dichroscope does not produce the colored rays, they emerge from the crystal and the calcite simply renders them more divergent so they can be seen at the same time.

As the dichroscope is turned each ray from the crystal is decomposed in the calcite and contributes a portion of its intensity to each of the two images, but at the positions of maximum difference of color the vibration directions of the two rays from the crystal and the vibration directions of the calcite coincide.

If one can be held back the o of a microscope is parallel an through and its color is seen. gets through and its color is seen.

In intermediate positions the

If it is desired to show ocular may be used, F dichroscope described b grains in thin sections.

### Determining Pleochroism

The colors of the ord trasted side by side by

FIG. 275.



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In some instrum at right angles to attached.

The section or s movable cap *C* by the light which ha

The instrumen which the crystal about two axes,

uniform slabs, tablets are easily The most con-



is projecting at thickness of about the wires can be and 297. See determination.

un-washed bottles; for flux will be needed by 1 1/2" by 1/4", or the most satisfac- includes Fig. 285.

FIG. 285.



are: bar magnet, with charcoal; lens and watch dishes, ivory spoon and Color Scale, p. 165; a monometer, Fig. 1.

## BLAST AND FLAME.

produced by the muscles of the distended cheeks, lungs.

sit erect, with the blowpipe held lightly but firmly and, and with the elbows against the sides. Then, distended and the mouth closed, place the mouth to the lips, breathe regularly through the nose, and into the pipe through the lips. From time to time admit air to the mouth from the throat. In this manner, turning to breathe through the nose while keeping the mouth closed, a continuous blast can be blown without

the flame (Fig. 286) usually shows three distinct por-

tion-luminous veil, *a*, of carbon and hydrogen.

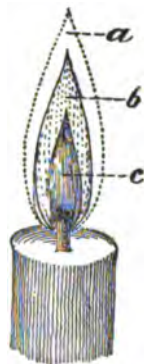
luminous mantle, *b*, of burning carbon.

cone, *c*, of unburned gases,

ing Flame.

is non-luminous, for luminous carbon, and hence a

FIG. 286.



flame, place the tip of the blowpipe just above the top of the burner, extending in  $\frac{1}{3}$  the breadth parallel to the burner top or wick until there is a blue flame nearly an inch long. This blue flame is just beyond the blue at *a* (Fig. 287) is nearly colorless zone, which is strongly oxidizing, and held in this usually as far from the tip of the blue flame as can be kept fluid. If the substance to be oxidized on charcoal, a weak blast must be used.

If one can be held back the other can be ground with a knife into uniform slabs, of a microscope is parallel an extinct which the tablets are easily gets through and its color is seen.

In intermediate positions the color is seen. The most con-

If it is desired to show the ocular may be used, Fig. 275. The dichroscope described below. grains in thin sections.

#### Determining Pleochroism with

The colors of the ordinary and trusted side by side by means of

FIG. 275.



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The instrument shown, Fig. 27 which the crystal, or section, or cu about two axes, one at right angl



platinum ends projecting at

The thickness of about the wires can be

Fig. 296 and 297.

silver determination. See

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connect to

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about  $1\frac{1}{2}$ " by  $1\frac{1}{2}$ " by  $\frac{1}{2}$ ", or

Fig. 284.

$\frac{1}{2}$ " or  $\frac{1}{4}$ "; the most satisfac-

Fig. 285.

Fig. 285.

Fig. 285.

Fig. 285.

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Fig. 285.

Fig. 285.

Fig. 285.

**BLAST AND FLAME.**

ed by the muscles of the distended cheeks,

with the blowpipe held lightly but firmly with the elbows against the sides. Then, ed and the mouth closed, place the mouth- breathe regularly through the nose, and e pipe through the lips. From time to r to the mouth from the throat. In this breathe through the nose while keeping continuous blast can be blown without

Fig. 286) usually shows three distinct por-

inous veil, *a*, of carbon

mantle, *b*, of burning

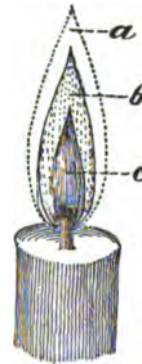
on.

*c*, of unburned gases,

e.

luminous, for lumi- carbon, and hence a

FIG. 286.



place the tip of the

top of the burner,

an  $\frac{1}{3}$  the breadth

the burner top or wick until there

nearly an inch long. This blue

beyond the blue at *a* (Fig. 287) is

zone, which is strongly oxidizing,

lly as far from the tip of the blue

id. If the substance to be oxi-

weak blast must be used.



## PART II.

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# BLOWPIPE ANALYSIS

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## CHAPTER XI.

### APPARATUS, BLAST, FLAME, ETC.

Qualitative determination of component elements and tests of fusibility and solubility are very important aids in the identification of mineral species, and together with a limited number tests with wet reagents are here discussed under the title of Blowpipe Analysis.

Bartholin, the describer of double refraction, appears to have been the first to utilize the blowpipe in mineral testing, for in 1670 he states that iceland spar before the blowpipe was burned to lime. Kunckel nine years later recommended its use in chemical testing. Its more systematic use in mineral testing dates from Anton Swab in 1733 and was developed at first in Sweden by Gahn, Cronstedt, Berzelius and others and later in Germany by Plattner, Richter, von Kobell and Bunsen.

#### **The Advantage of "Blowpipe Tests."**

Minerals are in general insoluble in water and many of them insoluble in acids. Their examination by wet methods would usually require a previous fusion and solution.

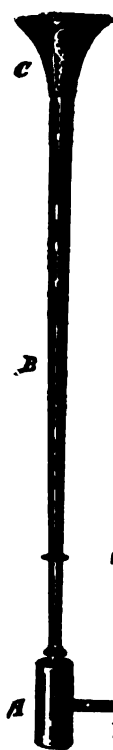
With the blowpipe the tests are made directly upon the mineral, and are rapidly obtained, with very little material and with very simple, easily portable apparatus and reagents.

Although group separations, except for instance into volatile and non-volatile, are not practicable the order of testing is not indifferent as it is often desirable that certain elements be detected and largely removed before making the tests for the others.

The set of apparatus which has been found best in the work at Columbia University consists of the following articles :

- |   |   |
|---|---|
| 1 Gas blowpipe, Plattner's, E & A No 794, modified.   | 1 Streak plate (fine grained) E & A 5310, size 2 1/8" x 3 3/8".       |
| 1 Forceps, platinum tipped, French style, E & A 3206.   | 2 Ft. rubber tubing, 1/8" I D, pure gum, E & A 6052.                  |
| 1 Cupel holder, 2 moulds, 1 stamp, E & A 829, made more convex by Columbia.   | 1 Dropping tube, pipette, small, E & A 5224.                          |
| 1 Steel hammer, Colton's, wire handled, E & A 3820.   | 6 Reagent bottles in wood block, with special short corks in bottles. |
| 1 Leed's Diamond mortar, E & A 4628, in wooden box.   | 3 Pieces charcoal, willow, close grained, best grade.                 |
| 1 Chisel and borer (combined) not magnetized, E & A 817.  | 1 Holder for platinum wire, E & A 831.                                |
| 1 Bar magnet in iron case, one end bevelled, Columbia make.   | 1 Platinum wire (6 inches) B & S No. 28.                              |
| 1 Coal tray, E & A 853, but size 5 1/2" x 4 1/2".   | 1 Outfit box, for carrying apparatus.                                 |
| 6 Watch glasses, 2" E & A 7832.   | 6 Inch white rubber tubing, 3/16" I D.                                |
| 12 Closed tubes—sublimation, closed at one end, O D 8 mm., I D 6 mm., length 100 mm. J. Kavalier's hard Bohemian combustion tubing. | 1 Box for hardness scale—New England Box Co.                          |
|   | 1 Merwin's flame color screen—G. M. Flint, Cambridge, Mass.           |
|   | 1 Penfield contact goniometer, model B, Sheffield Scientific School.  |
|   | 1 Coddington lens, 10X, Bausch & Lomb No. 162.                        |
|   | 1 File, 1/8" x 3" x 1/8".   |

#### The Blowpipe.—



The best form of blowpipe (Fig. 278) consists of :  
1. A tapering tube of brass or German silver (*B*), of a length proportionate to the eyesight of the user.

2. A horn or hard rubber mouthpiece (*C*) at the larger end of the tube. This should be of trumpet-shape to fit against the lips.

3. A moisture chamber (*A*) at the smaller end of the tube connected by ground joints to :

4. A tapering jet (*b*) at right angles to the moisture chamber.

5. A tip of platinum or brass (*c*), shown enlarged, which should be bored from a solid piece, and with an orifice of 0.5 millimeter diameter. The tip is by far the most important part of the blowpipe, and, if correctly made, the flame produced will be perfectly regular and will not flutter.

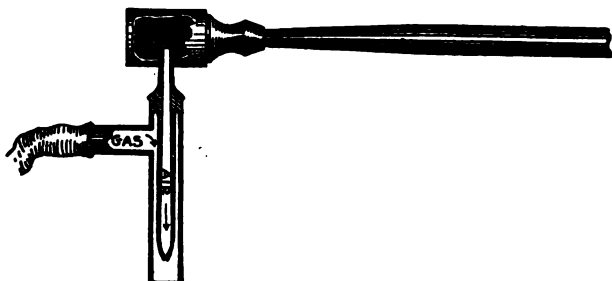
When not in use the blowpipe should be so placed that the tip is supported free from contact. If the tip is clogged by smoke or otherwise is should be burned out or cleaned with the greatest care so as not to injure the regular form of the orifice.

FIG. 278.

**Gas Blowpipe.**

For most purposes the gas blowpipe, Fig. 279, is a convenient form and is extensively used. The flame is not quite so hot as that from rape-seed oil, but is sufficient to round the edges of a calamine splinter. Oxidation and reduction are easily obtained and the cleanliness and ease of control cause it to be preferred by

FIG. 279.



many. The ordinary blowpipe can be made into a gas blowpipe by means of an attachment to connect to the moisture chamber.

**Blowpipe Lamps.**

*Bunsen Burner.* — The simplest form of lamp for laboratory pur-

FIG. 280.

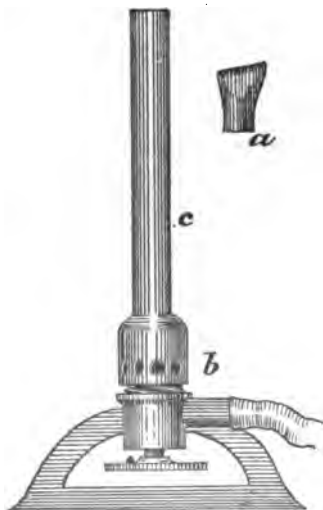
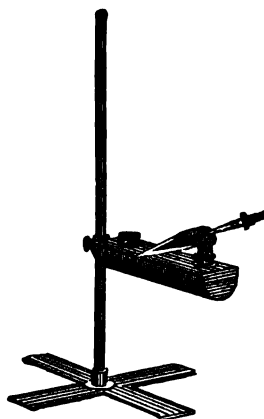


FIG. 281.



poses is the ordinary Bunsen burner, Fig. 280, using gas and furnished with a special top (*a*), or an inner tube shaped to spread

the flame. When used with the blowpipe the orifices ( $\delta$ ) at the bottom of the burner should be closed, so that no air enters with the gas. A flame about 4 cm. high gives the best results.

The hottest flame and greatest variations in quantity and quality of flame are obtained from oils rich in carbon, such as refined rapeseed, or olive or lard oil, or from mixtures of turpentine and alcohol. These can be used in the field and where gas is not available. In some kinds of blowpipe work they are to be preferred to gas, but will not serve for bending glass or for heating without the blowpipe.

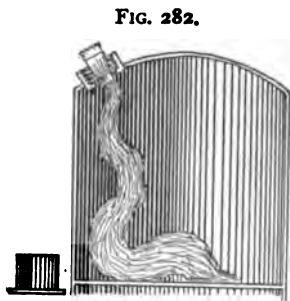
*Berzelius Lamp.* — A lamp with two openings, Fig. 281, is generally used for oil.

The wick should be soft, close-woven and cylindrical, such as is used with Argand lamps. It should be folded and inserted with the opening toward the lower side of the brass holder.

To fill the lamp both caps are removed and the oil poured in through the smaller orifice. During work, the smaller cap is hung on the vertical rod; the larger is placed over the smaller orifice loosely, keeping out the dust, but admitting the needed air.

The lamp is lighted by blowing a flame up and across the wick. When well charred, the wick is carefully trimmed parallel to the brass holder.

*Fletcher Lamp.* — The Fletcher blowpipe lamp, Fig. 282, gives good satisfaction, and a modified form, burning solid fats, tallow or paraffine, is especially adapted for field work.



#### Supports of Charcoal, Plaster, Etc.

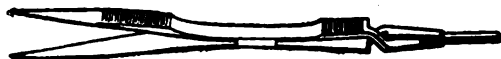
*Charcoal.* — Charcoal made from soft woods, such as willow or pine, is used to support the substance and receive any coats or sublimates that may form, and, in a measure, is a reducing agent. A convenient size is 4 inches long, 1 inch broad, and  $\frac{5}{8}$  inch thick.

*Plaster.* — Plaster tablets are used for the same purpose. These are prepared by making a paste of plaster of Paris and water, just thick enough to run, which is spread out upon a sheet of oiled glass and smoothed to a uniform thickness ( $\frac{1}{8}$ " to  $\frac{1}{4}$ ") by another smaller sheet of glass, which may be conveniently handled by gumming a large cork to one side and using it as a plasterer's trowel.

While still soft, the paste is cut with a knife into uniform slabs, 4" by 1½". It is then dried, after which the tablets are easily detached.

FORCEPS, with platinum tips for fusion tests. The most con-

FIG. 283.



venient form is shown, Fig. 283, the platinum ends projecting at least three fourths of an inch.

PLATINUM WIRE AND HOLDER.—Wire of the thickness of about one quarter millimeter and a holder in which the wires can be changed and with a receptacle for a stock of wires.

CLOSED AND OPEN TUBES. See Figs. 296 and 297.

CUPEL HOLDER AND CUPELS, for silver determination. See Figs. 403 and 404.

#### Miscellaneous Apparatus:

REAGENT BOTTLES.—Eight 2-oz. wide-mouthed bottles; for borax, soda, salt of phosphorus, and bismuth flux will be needed at all times in a convenient stand.

ANVIL.—Slab of polished steel, about 1½" by 1½" by ½", or better a Leeds diamond mortar, Fig. 284.

HAMMER.—Steel, with square face, ¾" or ½"; the most satisfactory being the Colton with wire handles, Fig. 285.

FIG. 284.



FIG. 285.



Other important pieces of apparatus are: bar magnet, with chisel edge; trays, for dirt and for charcoal; lens and watch glasses; cutting pliers; small porcelain dishes, ivory spoon and dropping tube.

Very useful accessories are the Merwin Color Scale, p. 165; a Hardness Scale, p. 217, and a Penfield Goniometer, Fig. 1.

**BLAST AND FLAME.****The Blast.**

The blast is produced by the muscles of the distended cheeks, and not by the lungs.

It is best to sit erect, with the blowpipe held lightly but firmly in the right hand, and with the elbows against the sides. Then, with the cheeks distended and the mouth closed, place the mouth-piece against the lips, breathe regularly through the nose, and allow air to pass into the pipe through the lips. From time to time, as needed, admit air to the mouth from the throat. In this manner, after learning to breathe through the nose while keeping the cheeks distended, a continuous blast can be blown without fatigue.

**The Flame.**

A LUMINOUS FLAME (Fig. 286) usually shows three distinct portions.

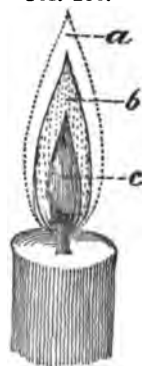
1. A very hot non-luminous veil, *a*, of carbon dioxide and free oxygen.
2. A yellow luminous mantle, *b*, of burning gases and incandescent carbon.
3. An interior dark cone, *c*, of unburned gases, not always visible.

**Oxidation and Oxidizing Flame.**

The oxidizing flame is non-luminous, for luminosity indicates unconsumed carbon, and hence a reducing action.

To produce such a flame, place the tip of the blowpipe almost touching the top of the burner, or the wick, and extending in  $\frac{1}{3}$  the breadth of the flame; blow parallel to the burner top or wick until there is produced a clear blue flame nearly an inch long. This blue flame is weakly reducing, but just beyond the blue at *a* (Fig. 287) is an intensely hot, nearly colorless zone, which is strongly oxidizing, and the bead is held in this usually as far from the tip of the blue flame as the bead can be kept fluid. If the substance to be oxidized is supported on charcoal, a weak blast must be used.

FIG. 286.



With the gas blowpipe all that is necessary is to avoid an excess of gas. The blue flame is, as before, surrounded by the oxidizing colorless mantle.

**Purity of Oxidizing Flame by Action on  $\text{MoO}_3$ .**

Regulate the supply of gas until the blowing produces a clear blue flame nearly an inch long. This blue flame itself is weakly reducing, but is surrounded by an intensely hot, nearly colorless zone, which is strongly oxidizing. The bead is held in the latter, Fig. 287, as far out from the tip as it will keep fluid.

Make a loop in platinum wire by bending it around a pencil point so that the end meets but does not cross the straight part,

FIG. 287.

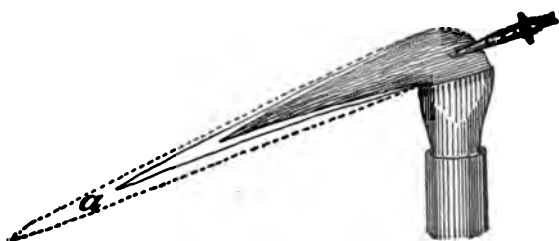


FIG. 288.



Fig. 288. Heat the loop, dip it into borax and fuse the portion that adheres to a clear bead. Add more borax until the bead is of full rounded shape.

Dip the hot bead into the  $\text{MoO}_3$ , dissolve the adhering material at the tip of the blue flame and make the bead alternately brown or black from  $\text{MoO}_2$  and colorless from  $\text{MoO}_3$  by *varying the position* of the bead in the flame.

**Purity of Reducing Flame by Action on  $\text{MnO}_2$ .**

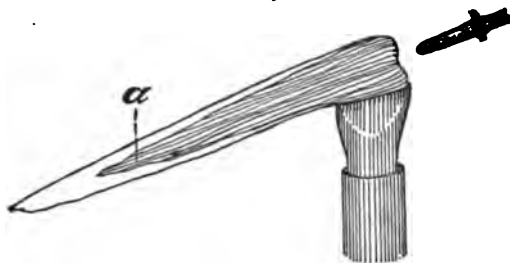
Regulate the gas to produce a larger flame than for the preceding test. This may be so done that during the blast there is still a distinctly yellow part near the end of the flame. The bead should be kept covered by this yellow portion, Fig. 289.

The blast must be continuous; too strong to produce a sooty flame, and not strong enough to oxidize by excess of air.

The blue flame also is reducing because of the carbon monoxide it contains, but it is not as effective.

Make a borax\* bead as in the preceding test. Dip it while hot into the  $\text{MnO}_2$  and heat in the oxidizing flame; if only a little  $\text{MnO}_2$  is used the bead will become violet-red when cold. It can be made colorless in the reducing flame by steady blowing. If

FIG. 289.



more is used the bead will be nearly black when cold before reduction and amethystine after reduction.

Or cupric oxide or oxide of nickel may be dissolved in a borax bead until the bead is opaque, and then reduced on charcoal to a clear bead and a metallic button.

---

\* When the flux is salt of phosphorus, the wire should be held over the flame so that the ascending hot gases will help to retain the flux upon the wire.



## CHAPTER XII.

### OPERATIONS OF BLOWPIPE ANALYSIS.

**Fusion.** The *degree* of fusibility and manner of fusion of a mineral are of great assistance in its determination.

The *degree* of fusibility is stated in terms of a scale of fusibility as suggested by von Kobell or sometimes in terms such as easily fusible, difficultly fusible.

The scale somewhat modernized is :

#### *Easily Fusible.*

1. *Stibnite* or *Sulphur*. Fuse in closed tube below red heat. Coarse splinters fuse in a candle or gas flame.
2. *Chalcopyrite* or *Galenite*. Fuse in closed tube at red heat. Standard splinters fuse in luminous flame.
3. *Garnet (Almandite)* or *Stilbite*. Standard splinters easily fuse before the blowpipe to a globule.
4. *Actinolite* or *Barite*. Standard splinters are easily rounded before the blowpipe. Fine splinters fuse easily to a globule.

#### *Difficultly Fusible*

5. *Orthoclase* or *Sphalerite*. Standard splinter rounded on thin edges before the blowpipe. Only finest splinters fused to a globule.
6. *Calamine* or *Enstatite*. Finest edges only rounded before blowpipe.

#### *Infusible.*

7. *Quartz* or *Topaz*. Retaining edges in all their sharpness after treatment.

**The Test.** The substance should be tried on coal to see if volatile or reducible. If not then as shown in Fig. 290, sharp edged thin splinters of some approximately constant size (say  $1\frac{1}{2} \times 4$  mm.) are held in the platinum forceps just beyond the tip of the blue flame.

If easily fused or reduced on coal, the platinum forceps must be avoided and the closed tube used (for 1 and 2).

If in powder, or with a tendency to crumble, grind and mix with water to fine paste, spread thin on coal and dry, and, if coherent, hold in the forceps.

The fragment should project beyond the platinum as in Fig. 290, so that heat may not be drawn off by the platinum, and the flame directed especially upon the point. It is always well to examine the splinter with a magnifying glass, before and after heating.

FIG. 290.



*The manner of fusion* may be such as to result in a glass or slag which is clear and transparent, or white and opaque, or of some color, or filled with bubbles. There may be a frothing or intumescence, or a swelling and splitting (exfoliation). In certain instances the color and form may change without fusion, etc.

**Flame Coloration.** A number of minerals when heated color the flame, some at a gentle heat, some only at the highest heat attainable. Repeated dipping of the mineral in hydrochloric acid usually assists by forming volatile chlorides. A good method to cover all cases is as follows: Arrange a black background, such as a piece of charcoal, powder the substance finely, flatten the end of a clean platinum wire and dip it in dilute acid, then in the powder, and hold it first just touching the flame near the blowpipe and then at the tip of the blue flame.

*Merwin's Color Scale* \* consisting of three colored strips of celluloid: No. 1, blue; No. 2, overlapping blue and violet; No. 3, violet, which absorb different portions of the spectrum is most satisfactory for distinguishing the red flames of calcium, strontium, lithium, and the violet flames of potassium in the presence of sodium. The sodium coloration is absorbed in all three, the observed colors for the rest in 1, 2, 3 order are

|                           |                 |                       |                       |
|---------------------------|-----------------|-----------------------|-----------------------|
| Potassium.....            | Blue-violet     | Violet and violet-red | Violet and violet-red |
| Calcium.....              | Greenish yellow | Absorbed              | Faint crimson         |
| Strontium or lithium..... | Absorbed        | Absorbed              | Crimson               |

\* *Science*, Vol. 30, p. 571.

The important flame colorations are :

**Yellows.**

**YELLOW.** — Sodium and all its salts. Invisible with blue glass.

**Reds.**

**CARMINE.** — Lithium compounds. Masked by soda flame. Violet through blue glass. Invisible through green glass.

**SCARLET.** — Strontium compounds. Masked by barium flame. Violet red through blue glass. Yellowish through green glass.

**YELLOWISH.** — Calcium compounds. Masked by barium flame. Greenish gray through blue glass. Green through green glass.

**Greens.**

**YELLOWISH.** — Barium compounds, molybdenum sulphide and oxide ; borates especially with sulphuric acid or boracic acid flux.

**PURE GREEN.** — Compounds of tellurium or thallium.

**EMERALD.** — Most copper compounds without hydrochloric acid.

**BLuish.** — Phosphoric acid and phosphates with sulphuric acid.

**FEEBLE.** — Antimony compounds. Ammonium compounds.

**WHITISH.** — Zinc.

**Blues.**

**LIGHT.** — Arsenic, lead and selenium.

**Azure.** — Copper chloride.

**WITH GREEN,** — Copper bromide and other copper compounds with hydrochloric acid.

**Violet.**

Potassium compounds. Obscured by soda flame. Purple red through blue glass. Bluish green through green glass. In silicates improved by mixing the powdered substance with an equal volume of powdered gypsum.

**USE OF THE SPECTROSCOPE.**

When salts of the same metal are volatilized in the non-luminous flame of a Bunsen burner the spectra produced, on decomposing the resultant light by a prism, will show lines identical in color, number and relative position. Salts of different metals will yield different lines.

Although, with pure salts, the already described flame colorations are generally distinct and conclusive, it will frequently happen that in silicates or minerals containing two or more reacting

substances the eye alone will fail to identify the flame coloration. It is well therefore to supplement the ordinary flame tests by spectroscopic observation. In the blowpipe laboratory the chief use of the spectroscope will be to identify the metals of the potassium and calcium families singly or in mixtures. For this purpose the direct vision spectroscope of Hoffman, Fig 291, is the most convenient.

The substance under examination should be moistened with hydrochloric acid and brought on a platinum wire into the non-luminous flame of the Bunsen burner as in the ordinary flame test. In viewing the flame through the properly adjusted spectroscope certain bright lines will be seen, and by comparing these with the chart, Fig. 294, or with substances of known composition, the nature of the substance may be determined. The sodium line will almost invariably be present and the position of the other lines will be best fixed by their situation relative to this bright yellow line.

The more ordinary form of spectroscope, Fig. 292, has special

FIG. 291.

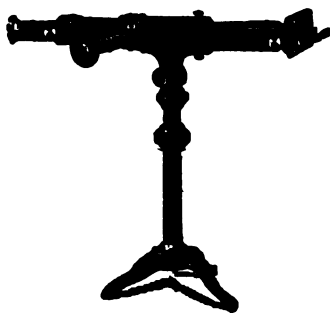
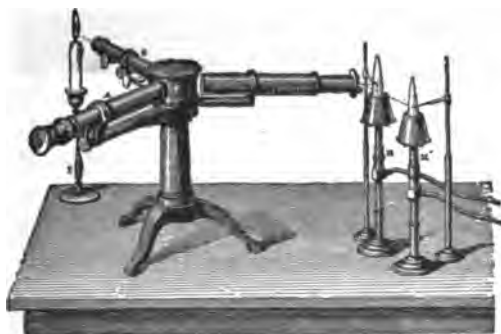
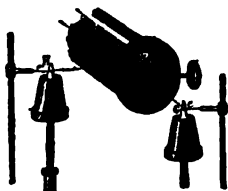


FIG. 292.



advantages in allowing an easy comparison of flames. *A* is the observation telescope, *B* the collimator through which the light from the flames *M* and *M'* is sent as parallel rays through the prism

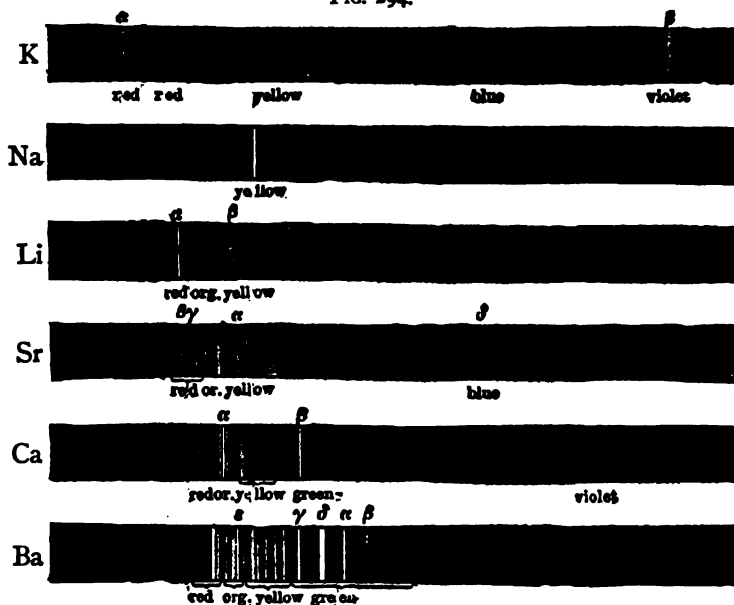
FIG. 293.



*P* to the telescope *A*. The third telescope *C* sends the image of a micrometer scale to *A* by which the relative distance apart of the lines is judged.

Fig. 293 shows an enlarged view of the collimator *B*. By means of the little rectangular prism *i* the light from a second flame *H*, placed at one side, is sent through the collimator and its spectrum obtained side by side with that from the flame *G*.

FIG. 294.



The chart (Fig. 294) and brief description of spectra of substances giving distinct lines with the Bunsen flame will be of service.

POTASSIUM — two red lines and one violet line.

SODIUM — a single bright yellow line, which with higher dispersion is resolved into two lines. Almost always present from the small amounts of sodium in dust.

LITHIUM — one very bright deep red line and a faint line in the orange.

STRONTIUM — a number of characteristic red lines and one blue line.

CALCIUM — a bright red, and a bright green line, with fainter red to yellow lines and a line in the violet.

BARIUM — a number of yellow and green lines.

*Absorption Spectra.*

The spectroscopic examination of the light reflected by or transmitted through colored minerals is likely to become of value in their identification.

The apparatus used may be a separate instrument such as the "Pocket Spectroscope" with absorption spectrum and normal spectrum side by side, and electrically illuminated wave-length scale or a spectroscope ocular for the microscope, and it must be possible to determine the position of the bands with accuracy.

The spectra obtained show often wide somewhat hazy black bands the position of which can be stated between limits and in other instances the series of very characteristic sharp bands which some can be closely placed.

In certain instances the bands are due to the presence of known coloring elements, uranium, the rare earths, chromium, vanadium, etc. In other instances the elements causing the colors are not known.

In certain species such as almandine garnet and zircon very characteristic lines are obtained, others like diamond sometimes give lines, sometimes do not.

**VOLATILIZATION.**

In blowpipe analysis, antimony, arsenic, cadmium, zinc, tin, lead, mercury and bismuth are always determined by securing sublimes of either the metals themselves or of some volatile oxide, iodide, etc.

Other elements and compounds, such as sulphur, selenium, tellurium, osmium, molybdenum, ammonia, etc., are also volatilized and in part determined during volatilization as odors or by sublimes. Certain other compounds, particularly chlorides of sodium and potassium and of some other metals, such as copper, tin and lead, yield sublimes ordinarily disregarded.

Volatilization tests are commonly obtained on charcoal, or plaster or in open and closed tubes.

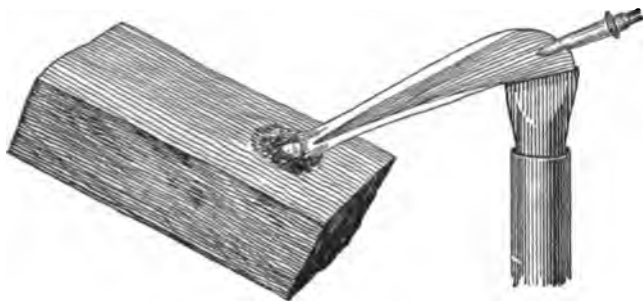
**Treatment on Charcoal.**

A shallow cavity, just sufficient to prevent the substance slipping, is bored at one end of the charcoal and a small fragment or a very little of the powdered substance is placed in it. The charcoal

is held in the left hand, so that the surface is at right angles to the lamp but tipped vertically at about  $120^\circ$  to the direction in which the flame is blown.

A gentle oxidizing flame is blown, the blue flame not touching the substance, but being just behind and in a line with it. After a

FIG. 295.



few moments the test is examined and all changes are noted, such as position and color of sublimate, color changes, odors, decrepitation, deflagration, formation of metal globules or magnetic particles. The heat is then increased and continued as long as the same reactions occur, but if, for instance, a sublimate of new color or position is obtained, it is often well to remove the first sublimate either by transferring the substance to another piece of charcoal or by brushing away the first formed sublimate after its satisfactory identification.

The same steps should then be followed using the reducing flame.

The sublimate differ in color and position on the charcoal; some are easily removed by heating with the oxidizing flame, some by the reducing flame, some are almost non-volatile, and some impart colors to the flame.

#### **Treatment on Plaster Tablets.**

Experience has shown that the sublimate obtained on charcoal and plaster supplement each other. The method of using is precisely the same and white sublimate are easily examined by first smoking the plaster surface by holding it in the lamp flame.

The coatings differ in position, and to some extent in color.

Plaster is the better conductor, condenses the oxides closer to the assay, and therefore, the more volatile coatings are thicker and more noticeable on plaster, while the less volatile coatings are more noticeable when spread out on charcoal. Charcoal supplements the reducing action of the flame, and therefore is the better support where strong reduction is desired.

**Comparison of Important Sublimates on Charcoal and Plaster.\***

**I. Without Fluxes.—Treated First in O. F., then in R. F.**

**ARSENIC.**—White volatile coat. On smoked plaster it is crystalline and prominent; on charcoal it is fainter and less distinct, but the odor of garlic is more marked. Deposits at some distance from assay. Fumes invisible close to assay.

**ANTIMONY.**—White pulverulent volatile coat, more prominent on charcoal. Is deposited near assay and the fumes are visible close to assay after removal of flame.

**SELENIUM.**

*On Charcoal.*—Horse-radish odor and a steel-gray coat.

*On Plaster.*—Horse-radish odor, brick-red to crimson coat.

**TELLURIUM.**

*On Charcoal.*—White coat with red or yellow border.

*On Plaster.*—Deep brown coat.

**CADMIUM.**

*On Charcoal.*—Brown coat surrounded by peacock tarnish.

*On Plaster.*—Dark brown coat shading to greenish-yellow and again to dark brown.

**MOLYBDENUM.**—Crystalline yellow and white coat with an outer circle of ultramarine blue. Most satisfactory on plaster.

**LEAD.**— } Yellow sublimate with outer fringe of white. More  
**BISMUTH.**— } noticeable on charcoal than on plaster.

**ZINC.**—White, not easily volatile coat, yellow while hot. Best on charcoal.

**TIN.**—White non-volatile coat close to assay, yellowish while hot. Best on charcoal.

---

\* Certain compounds give a white coating before the blowpipe which at times cause confusion. Among these are many chlorides and the sulphate of lead. Galena and lead sulphides also give white sublimates which must not be confused with the arsenic or antimony coats.



**II. With Bismuth Flux.\*****LEAD.**

*On Plaster.*—Chrome yellow coat.

*On Charcoal.*—Greenish-yellow, equally voluminous coat.

**BISMUTH.**

*On Plaster.*—Chocolate-brown coat, with an underlying scarlet; with ammonia it becomes orange-yellow, and later cherry-red.

*On Charcoal.*—Bright red band with a fringe of yellow.

**MERCURY.**

*On Plaster.*—Scarlet coat with yellow, but if quickly heated is dull yellow and black.

*On Charcoal.*—Faint yellow coat.

**ANTIMONY.**

*On Plaster.*—Orange coat stippled with peach-red.

*On Charcoal.*—Faint yellow coat.

**ARSENIC.**

*On Plaster.*—Yellow and orange coat, and not usually satisfactory.

*On Charcoal.*—Faint yellow coat.

**TIN.**

*On Plaster.*—Brownish-orange coat.

*On Charcoal.*—White coat.

The following tests show only on the plaster :

**SELENIUM.**—Reddish-brown, nearly scarlet.

**TELLURIUM.**—Purplish-brown with darker border.

**MOLYBDENUM.**—Deep ultramarine blue.

**III. With Soda (Sodium Carbonate or Bicarbonate).**

Soda on charcoal exerts a reducing action partly by the formation of sodium cyanide, partly because the salts sink into the charcoal and yield gaseous sodium and carbon monoxide. The most satisfactory method is to mix the substance with three parts of the moistened reagent and a little borax; then spread on the charcoal and treat with a good reducing flame until everything that can be absorbed has disappeared. Moisten the charcoal with water, break out and grind the portion containing the charge. Wash away the lighter part and examine the residue for scales and magnetic particles.

---

\* Two parts of sulphur, one part of potassium iodide, one part of acid potassium sulphate.

The reduction may result in:

1. *Coating, but no reduced metal.*

Volatile white coating and garlic odor, . . . . . **As.**

Reddish-brown and orange coating with characteristic  
variegated border, . . . . . **Cd.**

Non-volatile coating, yellow hot and white cold, . . . **Zn.**

Volatile steel-gray coating and horseradish odor, . . . **Se.**

Volatile white coating with reddish border, . . . . . **Te.**

2. *Coating with reduced metal.*

Volatile thick white coating and gray brittle button, . **Sb.**

Lemon-yellow coating and reddish-white brittle button, **Bi.**

Sulphur-yellow coating and gray malleable button, . . **Pb.**

Non-volatile white coating, yellow hot, and malleable  
white button, . . . . . **Sn.**

White coating, made blue by touch of R. F., and gray  
infusible particles, . . . . . **Mo.**

3. *Reduced metal only.*

Malleable buttons, . . . . . **Cu, Ag, Au.**

Gray magnetic particles, . . . . . **Fe, Co, Ni.**

Gray non-magnetic infusible particles, **W, Pt, Pd, Ir, Rh.**

The carbonate combines with many substances forming both fusible and infusible compounds. Many silicates dissolve with a little of the reagent, but with more are infusible; a few elements form colored beads with the reagent, especially on platinum.

The residue left after heating may contain malleable metallic beads of copper, lead, silver, tin or gold. It may consist of a brittle easily fusible button of bismuth, antimony, or the sulphide, arsenide or antimonide of some metal. It may be magnetic from the presence of iron, cobalt or nickel or it may show an alkaline reaction, when touched to moistened red litmus or tumeric paper, indicating the presence of some member of the potassium or calcium group of metals.

*Infusible Compounds.*—Mg, Al, Zr, Th, Y, Gl.

*Fusible Compounds.*—SiO<sub>2</sub> effervesces and forms a clear bead that remains clear on cooling if the reagent is not in excess.

TiO<sub>2</sub> effervesces and forms a clear yellow bead crystalline and opaque on cooling:

WO<sub>3</sub> and MoO<sub>3</sub> effervesce but sink in the charcoal.

Ba, Sr, Ta, V, Nb sink into the charcoal.

Ca fuses, then decomposes, and the soda sinks into the charcoal.

*Colored Beads.*—Mn forms a turquois or blue-green opaque bead with soda on platinum wire in the oxidizing flame.

Cr forms a chrome-yellow opaque bead with soda on platinum wire in the oxidizing flame, which becomes green in reducing flame.

*Sulphur Reaction.*—If a little of the residue, with some of the charcoal beneath, is taken up upon the point of a knife and placed upon a wet silver coin, the coin will be blackened if sulphur was present as a sulphide. Sulphates and other sulphur compounds will also give the same reaction after thorough fusion. The test should always be made on a fresh piece of charcoal.

#### IV. With Metallic Sodium.

Reducing effects which are obtained with soda only by hard blowing may be accomplished by the use of metallic sodium immediately and with the greatest ease. The metal should be handled carefully and not allowed to come in contact with water. It should be kept in small tightly closed bottles, and if kept covered with naphtha, which is not necessary, care should be taken that the naphtha is not exposed to fire.

A cube of sodium about a quarter-inch in diameter is cut off with a knife and hammered out flat. The powdered substance is placed upon the sodium, pressed into it and the whole moulded into a little ball with a knife blade. This sodium ball should not be touched with the fingers, for if some oxides are present, such as lead oxide, spontaneous combustion may take place. After placing the sodium ball on the charcoal it should be touched carefully with a match or with the Bunsen flame. A little flash ensues and the reduction is accomplished. The residue can now be safely heated with the reducing flame of the blowpipe, any reduced metal collected together and the sodium compounds volatilized or absorbed by the charcoal. When present in sufficient quantity, beads of the malleable metals can be obtained immediately from almost any of their mineral compounds; metals, like zinc and tin, which require reduction before volatilization yield their sublimates with comparative ease; and if a little of the charcoal beneath the assay is placed on a wet silver coin the sulphur reaction will be obtained if sulphur was present.

In general the results are the same as outlined for soda but are much more easily secured.

Even silica, silicates, borates, etc., are reduced but are generally identified by other means.

These reactions are not successful on plaster tablets on account of their non-absorbent character.

### Tests in Closed Tubes.

A plain narrow glass tube about 4 inches by  $\frac{1}{4}$  inch and closed at one end is best. The usual purposes are to note the effects of heat without oxidation, and to effect fusions with such reagents as  $\text{KHSO}_4$  or  $\text{KClO}_3$ .

Enough of the substance is slid down a narrow strip of paper, previously inserted in the tube, to fill it to the height of about one half inch; the paper is withdrawn and the slightly inclined tube, Fig. 296, heated at the lower end gradually to a red heat. The results may be: evolution of water, odorous and non-odorous vapors, sublimes of various colors, decrepitation, phosphorescence, fusion, charring, change of color, and magnetization.

FIG. 296.



|  |                        |
|--|------------------------|
| Acid or alkaline moisture in the upper part of tube, . . . . .                       | $\text{H}_2\text{O}$ . |
| Odorless gas that assists combustion (nitrates, chlorates and per oxides), . . . . . | $\text{O}$ .           |
| Pungent gas that whitens lime water, . . . . .                                       | $\text{CO}_2$ .        |

### Odors.

|  |                        |
|--|------------------------|
| Odor of prussic acid, . . . . .                                    | $\text{CN}$ .          |
| Odor of putrid eggs, . . . . .                                     | $\text{H}_2\text{S}$ . |
| Odor that suffocates, fumes colorless, bleaching action, . . . . . | $\text{SO}_2$ .        |
| Odor that suffocates, fumes violet, . . . . .                      | $\text{I}^*$ .         |
| fumes brown, . . . . .   | $\text{Br}$ .          |
| fumes greenish yellow, . . . . .                                   | $\text{Cl}$ ,          |
| fumes etch the glass, . . . . .                                    | $\text{F}$ .           |
| Odor of nitric peroxide, fumes reddish-brown, . . . . .            | $\text{NO}_2$ .        |
| Odor of ammonia, fumes colorless or white, . . . . .               | $\text{NH}_3$ .†       |

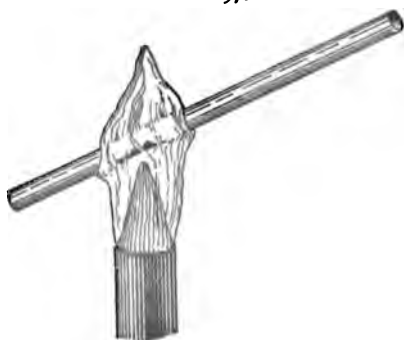
\*  $\text{I}$ ,  $\text{Br}$ ,  $\text{Cl}$ ,  $\text{F}$  and  $\text{N}_2\text{O}_5$  are assisted by mixing substance with acid potassium sulphate.  
 †  $\text{NH}_3$ ,  $\text{Hg}$ ,  $\text{As}$ ,  $\text{Cd}$  are assisted by mixing with soda.

**Sublimates.**

|  |                           |
|--|---------------------------|
| Sublimate white, fusing yellow, . . . . .                      | $\text{PbCl}_2$ .         |
| fusing to drops, disagreeable odor, . . . . .                  | Os.                       |
| and volatile, . . . . .  | $\text{NH}_4$ (salts).    |
| yellow hot, infusible, . . . . .                               | $\text{HgCl}_2$ .         |
| yellow hot, fusible, . . . . .                                 | $\text{HgCl}_2$ .         |
| fusible, needle crystals, . . . . .                            | $\text{Sb}_2\text{O}_3$ . |
| volatile, octahedral crystals, . . . . .                       | $\text{As}_2\text{O}_3$ . |
| fusible, amorphous powder, . . . . .                           | $\text{TeO}_2$ .          |
| Sublimate mirror-like, collects in globules, . . . . .         | Hg.                       |
| does not collect in globules, . . . . .                        | As, Cd, Te.               |
| Sublimate red when hot, yellow cold, . . . . .                 | S.                        |
| Sublimate dark red when hot, reddish-yellow cold, . . . . .    | $\text{As}_2\text{S}_3$ . |
| Sublimate black when hot, reddish-brown cold, . . . . .        | $\text{Sb}_2\text{S}_3$ . |
| Sublimate black, but becomes red when rubbed, . . . . .        | $\text{HgS}$ .            |
| Sublimate red to black, but becomes red when rubbed, . . . . . | Se.                       |
| Color of substances changes                                    |                           |
| from white to yellow, cools yellow, . . . . .                  | $\text{PbO}$ .            |
| from white to yellow, cools white, . . . . .                   | $\text{ZnO}$ .            |
| from white to dark yellow, cools light yellow, . . . . .       | $\text{Bi}_2\text{O}_3$ . |
| from white to brown, cools yellow, . . . . .                   | $\text{SnO}_2$ .          |
| from white to brown, cools brown, . . . . .                    | $\text{CdO}$ .            |
| from yellow or red to darker, after strong heat, . . . . .     |                           |
| cools green, . . . . .   | $\text{Cr}_2\text{O}_3$ . |
| from red to black, cools red, . . . . .                        | $\text{Fe}_2\text{O}_3$ . |
| from blue or green to black, cools black, . . . . .            | $\text{CuO}$ .            |

**Tests in Open Glass Tubes.**

FIG. 297.



By using a somewhat longer tube, open at both ends and held in an inclined position, a current of air is made to pass over the heated substance, and thus many substances not volatile in themselves absorb oxygen and release volatile oxides. The substance should be in state of powder.

Place the assay near the lower

end of the tube, Fig. 297, and heat gently, and then strongly, increasing the air current by holding the tube more and more nearly vertical.

|   |   |  |
|---|---|--|
| Odor that suffocates, bleaching action, . . . . .   | $\text{SO}_2$ , indicating <b>S</b> .   |  |
| Odor of rotten horseradish, . . . . .   | $\text{SeO}_2$ , " <b>Se</b> .          |  |
| Odor of garlic, . . . . .   | $\text{As}_2\text{O}_3$ , " <b>As</b> . |  |
| Sublimate white volatile octahedral crystals, . . . . .   | $\text{As}_2\text{O}_3$ , " <b>As</b> . |  |
| Sublimate white partially volatile, fusible to yellow drops, pearl gray cold, . . . . .         | $\text{PbOCl}_2$ , " <b>PbCl}_2</b> .   |  |
| Sublimate white non-volatile powder, dense fumes, . . . . .                                     | $\text{Sb}_2\text{O}_3$ , " <b>Sb</b> . |  |
| Sublimate white non-volatile powder, fusible to colorless drops, . . . . .                      | $\text{TeO}_2$ , " <b>Te</b> .          |  |
| Sublimate white non-volatile powder, fusible to yellow drops, white when cold, . . . . .        | $\text{PbSO}_4$ , " <b>PbS</b> .        |  |
| Sublimate white non-volatile fusible powder, . . . . .  | $\text{BiSO}_4$ , " <b>BiS</b> .        |  |
| Sublimate gray, red at distance, . . . . .  | $\text{SeO}_2$ , " <b>Se</b> .          |  |
| Sublimate yellow hot, white cold, crystalline near the assay, blue in reducing flame, . . . . . | $\text{MoO}_3$ , " <b>Mo</b> .          |  |
| Sublimate brown hot, yellow cold, fusible, . . . . .  | $\text{Bi}_2\text{O}_3$ , " <b>Bi</b> . |  |
| Sublimate metallic mirror, . . . . .  | " <b>Hg</b> .                           |  |

#### **Bead Tests with Borax and with Salt of Phosphorus.**

Preliminary to bead tests, many compounds, sulphides, arsenides, arsenates, etc., may be converted into oxides by roasting as follows :

Treat in a shallow cavity on charcoal at a dull red heat, never allowing the substance to fuse or even sinter. Use a feeble oxidizing flame to drive off sulphur, then a feeble reducing flame to reduce arsenical compounds, then reheat in an oxidizing flame. Turn, crush, and reroast until no sulphurous or garlic odor is noticeable.

Sodium tetraborate or borax may be considered as made up of sodium metaborate and boron trioxide. The boron trioxide at a high temperature combines with metallic oxides, driving out volatile acids, and by the aid of the oxidizing flame the resulting borates fuse with the sodium metaborate to form double borates which are often of a characteristic color. The color may differ when hot and cold and according to the degree of oxidation and reduction.

Sodium ammonium phosphate, or salt of phosphorus, by fusion loses water and ammonia and becomes sodium metaphosphate. The sodium metaphosphate at high temperatures combines with metallic oxides to form double phosphates and pyrophosphates, which like the double borates are frequently colored, although the colors often differ from those obtained with borax.

A bead of either flux is made on platinum wire as described on page 162, and the substance is added gradually to the warm bead and fused with it in the oxidizing flame. The ease of dissolving, effervescence, color, change of color, etc., should be noted.

We may greatly simplify the tabulation of results by the following division :

*1. Oxides which Color neither Borax or Salt of Phosphorus, or at Most Impart a Pale Yellow to the Hot Bead when Added in Large Amounts.*

| OXIDES OF  | NOTICEABLE DISTINCTIONS.  |
|------------|---|
| ALUMINUM.  | —Cannot be flamed opaque.   |
| ANTIMONY.  | —Yellow hot in oxidizing flame, flamed opaque gray in reducing flame, on charcoal with tin black. Expelled by reducing flame in time. |
| BARIUM.    | —Flamed opaque white.   |
| BISMUTH.   | —Like antimony.   |
| CADMIUM.   | —Like antimony, but not made black by fusion with tin.  |
| CALCIUM.   | —Like barium.   |
| LEAD.      | —Like antimony, but not made black by fusion with tin.  |
| MAGNESIUM. | —Like barium.   |
| SILICON.   | —Only partially dissolved in salt of phosphorus.  |
| STRONTIUM. | —Like barium.   |
| TIN.       | —Like aluminum.   |
| ZINC.      | —Like antimony, but not made black by fusion with tin.  |

*2. Oxides which Impart Decided Colors to the Beads.*

The colors in hot and cold beads of both fluxes and under both oxidation and reduction are shown in the following table. The abbreviations are : sat = saturated ; fl = flamed ; op = opaque.

Hot and cold relate to same bead ; *hot* and *cold* to larger amounts of the oxide.

| BORAX BEADS. | OXIDES OF   |              | VIOLET.  | BLUE.                  | GREEN.            | RED.              | BROWN.           | YELLOW.                  | COL'L'SS          |
|--------------|-------------|--------------|----------|------------------------|-------------------|-------------------|------------------|--------------------------|-------------------|
|              | Chromium,   | O.F.<br>R.F. |          |                        | cold<br>hot, cold | <i>hot</i>        |                  | hot                      |                   |
|              | Cobalt,     | O.F.<br>R.F. |          | hot, cold<br>hot, cold |                   |                   |                  |                          |                   |
|              | Copper,     | O.F.<br>R.F. |          | cold                   | hot               | <i>cold</i> (op.) | cold             |                          | hot               |
|              | Iron,       | O.F.<br>R.F. |          |                        | hot, cold         | <i>hot</i>        |                  | <i>hot, cold</i>         | cold              |
|              | Manganese,  | O.F.<br>R.F. | hot cold |                        |                   |                   | <i>cold</i>      |                          | hot, cold         |
|              | Molybdenum, | O.F.<br>R.F. |          |                        |                   | hot (sat.)        | hot, cold        | hot                      | cold              |
|              | Nickel,     | O.F.<br>R.F. | hot      |                        |                   |                   | cold             |                          | hot, cold         |
|              | Titanium,   | O.F.<br>R.F. |          | flamed                 |                   |                   | <i>hot, cold</i> | <i>hot</i><br>hot, cold  | hot, cold         |
|              | Tungsten,   | O.F.<br>R.F. |          |                        |                   |                   | cold             | <i>hot</i> (sat.)<br>hot | hot, cold<br>cold |
|              | Uranium,    | O.F.<br>R.F. |          |                        | hot, cold         | hot               |                  | hot, cold (fl.)          |                   |
|              | Vanadium,   | O.F.<br>R.F. |          |                        | cold              |                   | hot              | <i>hot, cold</i>         | hot, cold         |

| SALT OF PHOSPHORUS BEADS. | OXIDES OF   |              | VIOLET.   | BLUE.                  | GREEN.            | RED.                           | BROWN.       | YELLOW.                 | COL'L'SS     |
|---------------------------|-------------|--------------|-----------|------------------------|-------------------|--------------------------------|--------------|-------------------------|--------------|
|                           | Chromium,   | O.F.<br>R.F. |           |                        | cold<br>cold      | hot<br>hot                     |              |                         |              |
|                           | Cobalt,     | O.F.<br>R.F. |           | hot, cold<br>hot, cold |                   |                                |              |                         |              |
|                           | Copper,     | O.F.<br>R.F. |           | cold<br>hot            | hot               | <i>cold</i> (op )              |              |                         |              |
|                           | Iron,       | O.F.<br>R.F. |           |                        |                   | <i>hot</i><br><i>hot, cold</i> | cold<br>cold | hot, <i>cold</i><br>hot | cold<br>cold |
|                           | Manganese,  | O.F.<br>R.F. | hot, cold |                        |                   |                                |              |                         | hot, cold    |
|                           | Molybdenum, | O.F.<br>R.F. |           |                        | hot<br>hot, cold  |                                |              |                         | cold         |
|                           | Nickel,     | O.F.<br>R.F. |           |                        |                   | hot<br>hot                     |              | cold<br>cold            |              |
|                           | Titanium,   | O.F.<br>R.F. | cold      |                        |                   |                                |              | <i>hot</i><br>hot       | hot, cold    |
|                           | Tungsten,   | O.F.<br>R.F. |           | cold                   | hot               |                                |              | hot (sat.)              | hot, cold    |
|                           | Uranium,    | O.F.<br>R.F. |           |                        | cold<br>hot, cold |                                |              | hot                     |              |
|                           | Vanadium,   | O.F.<br>R.F. |           |                        | cold              |                                | hot          | hot, cold               |              |



**FLAMING.**

Some substances yield a clear glass with borax or salt of phosphorus, which remains clear when cold, but at a certain point near saturation if heated slowly and gently or with an intermittent flame, or unequally, or by alternate oxidizing flame and reducing flame, the bead becomes opaque and enamel-like.

**Testing Solubility.**

**Solubility in Water.**—Ordinarily the absence of a taste or of some evidence of exposure such as a dull surface or damp condition or tendency to fall to powder or even a hardness above 3 prove insolubility in water.

But as recognition of the kind of taste is not usually easy it is better to heat the powdered substance with water and allow several drops of the solution to evaporate on a glass slip, usually obtaining a very characteristic recrystallization either of the original substance or crystals of some new compound.

**Solubility in Dilute Hydrochloric Acid.**—Dilute (1:1) hydrochloric acid is generally used to determine the ease or degree of solubility. This test fails only from carelessness. The substance must be selected as nearly pure as possible, finely ground and added to the acid in successive small quantities. <sup>The acid should be heated</sup> A clear solution should be aimed at, acid being added if more is needed until everything has dissolved. If complete solution cannot be obtained, the liquid must be filtered and the clear filtrate slowly and partially evaporated until separation commences. If doubt exists as to solubility the *liquid must be evaporated to dryness*, a residue proving solution to have taken place.

During the treatment carbonates and some sulphides are decomposed and  $\text{CO}_2$  or  $\text{H}_2\text{S}$  escapes with effervescence. The odor of  $\text{H}_2\text{S}$  is easily recognized. Some silicates will yield on *partial* evaporation a cake of jelly, others lumps of jelly, others fine pulverulent silica. Still other minerals may form characteristic crystals or residues.

**Effect of Concentrated Hydrochloric Acid.**—With a glass rod place a single drop of acid on a smooth surface of the mineral (or upon an object glass, adding a few particles of the powdered mineral). Let this acid nearly dry, and examine under the microscope.

**Effect of Dilute Hydrofluoric Acid.**—Some minerals unaffected by other acids are dissolved by this. Dip the stone in melted paraffine and mark a cross or other convenient shape through the paraffine above some unimportant face. Immerse for  $\frac{1}{2}$  hour in the acid (1 c.p. acid and 2 water), remove, wash, and clean off the paraffine. If the cross shows, then the mineral is soluble.

#### **Tests with Cobalt Solution.**

Cobalt nitrate dissolved in ten parts of water is used to moisten light colored infusible substances. These are then strongly heated on charcoal in the oxidizing flame and colored compounds result.

BLUE,  $Al_2O_3$ , and minerals containing it. Silicates of zinc.

GREEN (bluish),  $SnO_2$ .

GREEN (yellowish),  $ZnO$ ,  $TiO_2$ .

GREEN (dark), oxides of antimony and columbium.

FLESH COLOR,  $MgO$ , and minerals containing it.

Certain other substances yield colors if strongly heated, cooled, and then moistened with the cobalt solution without reheating. Certain minerals boiled with cobalt solution are colored thereby.

## CHAPTER XIII.

### SUMMARY OF USEFUL TESTS WITH THE BLOWPIPE.

THE details of ordinary manipulations, such as obtaining beads, flames, coatings and sublimates, are omitted and the results alone stated; unusual manipulations are described. The bead tests are supposed to be obtained with oxides; the other tests are true, in general, of all compounds not expressly excluded. The course to be followed in the case of interfering elements is briefly stated.

#### ALUMINUM, Al.

*With Soda.*—Swells and forms an infusible compound.

*With Borax or S. Ph.*—Clear or cloudy, never opaque.

*With Cobalt Solution.\**—Fine blue when cold.

#### AMMONIUM, NH<sub>4</sub>.

*In Closed Tube.*—Evolution of gas with the characteristic odor. Soda or lime assists the reaction. The gas turns red litmus paper blue and forms white clouds with HCl vapor.

#### ANTIMONY, Sb.

*On Coal, R. F.†*—Volatile white coat, bluish in thin layers, continues to form after cessation of blast and appears to come directly off the mass.

*With Bismuth Flux:*

*On Plaster.*—Peach-red coat, somewhat mottled.

*On Coal.*—Faint yellow or red coat.

---

\* Certain phosphates, borates and fusible silicates become blue in absence of alumina.

† This coat may be further tested by S Ph. or flame.

*In Open Tube.*—Dense, white, non-volatile, amorphous sublimate. The sulphide, too rapidly heated, will yield spots of red.

*In Closed Tube.*—The oxide will yield a white fusible sublimate of needle crystals, the sulphide, a black sublimate red when cold.

*Flame.*—Pale yellow-green.

*With S. Ph.*—Dissolved by O. F. and fused on coal with tin in R. F. becomes gray to black.

#### INTERFERING ELEMENTS.

*Arsenic.*—Remove by gentle O. F. on coal.

*Arsenic with Sulphur.*—Remove by gentle heating in closed tube.

*Copper.*—The S. Ph. bead with tin in R. F. may be momentarily red but will blacken.

*Lead or Bismuth.*—Retard formation of their coats by intermittent blast, or by adding boracic acid. Confirm coat by flame, not by S. Ph.

#### ARSENIC, As.

*On Smoked Plaster.*—White coat of octahedral crystals.

*On Coal.*—Very volatile white coat and strong garlic odor. The oxide and sulphide should be mixed with soda.

*With Bismuth Flux:*

*On Plaster.*—Reddish orange coat.

*On Coal.*—Faint yellow coat.

*In Open Tube.*—White sublimate of octahedral crystals. Too high heat may form deposit of red or yellow sulphide.

*In Closed Tube.*—May obtain white oxide, yellow or red sulphide, or black mirror of metal. If the tube is broken and the mirror heated, a strong garlic odor will be noticed.

*Flame.*—Pale azure blue.

#### INTERFERING ELEMENTS.

*Antimony.*—Heat in closed tube with soda and charcoal, break and treat resulting mirror in O. F. for odor.

*Cobalt or Nickel.*—Fuse in O. F. with lead and recognize by odor.

*Sulphur.*—(a) Red to yellow sublimate of sulphide of arsenic in closed tube.

(b) Odor when fused with soda on charcoal.

**BARIUM, Ba.**

*On Coal with Soda.*—Fuses and sinks into the coal.

*Flame.*—Yellowish green improved by moistening with HCl.

*With Borax or S. Ph.*—Clear and colorless, can be flamed opaque-white.

**BISMUTH, Bi.**

*On Coal.*—In either flame is reduced to brittle metal and yields a volatile coat, dark orange yellow hot, lemon yellow cold, with yellowish-white border.

*With Bismuth Flux* :\*

*On Plaster.*—Bright scarlet coat surrounded by chocolate brown, with sometimes a reddish border. The brown may be made red by ammonia.†

*On Coal.*—Bright red coat with sometimes an inner fringe of yellow.

*With S. Ph.*—Dissolved by O. F. and treated on coal with tin in R. F. is colorless hot but blackish gray and opaque cold.

**INTERFERING ELEMENTS.**

*Antimony.*—Treat on coal with boracic acid, and treat the resulting slag on plaster with bismuth flux.

*Lead.*—Dissolve coat in S. Ph. as above.

**BORON, B.**

All borates intumesce and fuse to a bead.

*Flame.*—Yellowish green. May be assisted by : (a) Moistening with  $H_2SO_4$ ; (b) Mixing to paste with water, and boracic acid flux ( $4\frac{1}{2}$  pts.  $KHSO_4$ , 1 pt.  $CaF_2$ ); (c) By mixing to paste with  $H_2SO_4$  and  $NH_4F$ .

**BROMINE, Br.**

*With S. Ph. Saturated With  $CuO$ .*—Treated at tip of blue flame, the bead will be surrounded by green and blue flames.

*In Matrass With  $KHSO_4$ .*—Brown choking vapor.

**INTERFERING ELEMENTS.**

*Silver.*—The bromide melts in  $KHSO_4$  and forms a blood-red globule which cools yellow and becomes green in the sunlight.

---

\* Sulphur 2 parts, potassic iodide 1 part, potassic bisulphate 1 part.

† May be obtained by heating S. Ph. on the assay.

**CADMIUM, Cd.**

*On Coal R. F.*—Dark brown coat, greenish yellow in thin layers. Beyond the coat, at first part of operation, the coal shows a variegated tarnish.

*On Smoked Plaster with Bismuth Flux.*—White coat made orange by  $(\text{NH}_4)_2\text{S}$ .

*With Borax or S. Ph.*—O. F. clear yellow hot, colorless cold, can be flamed milk-white. The hot bead touched to  $\text{Na}_2\text{S}_2\text{O}_3$  becomes yellow.

R. F. Becomes slowly colorless.

**INTERFERING ELEMENTS.**

*Lead, Bismuth, Zinc.*—Collect the coat, mix with charcoal dust and heat gently in a closed tube. Cadmium will yield either a reddish brown ring or a metallic mirror. Before collecting coat treat it with O. F. to remove arsenic.

**CALCIUM, Ca.**

*On Coal with Soda.*—Insoluble and not absorbed by the coal.

*Flame.*—Yellowish red improved by moistening with HCl.

*With Borax or S. Ph.*—Clear and colorless, can be flamed opaque.

**CARBON DIOXIDE,  $\text{CO}_2$ .**

*With Nitric Acid.*—Heat with water and then with dilute acid.  $\text{CO}_2$  will be set free with effervescence. The escaping gas will render lime-water turbid.

*With Borax or S. Ph.*—After the flux has been fused to a clear bead, the addition of a carbonate will cause effervescence during further fusion.

**CHLORINE, Cl.**

*With S. Ph. Saturated with  $\text{CuO}$ .*—Treated at tip of blue flame, the bead will be surrounded by an intense azure-blue flame.

*On Coal with  $\text{CuO}$ .*—Grind with a drop of  $\text{H}_2\text{SO}_4$ , spread the paste on coal, dry gently in O. F. and treat with blue flame, which will be colored greenish-blue and then azure-blue.

**CHROMIUM, Cr.**

*With Borax or S. Ph.*—O. F. Reddish hot, fine yellow-green cold.

R. F. In borax, green hot and cold. In S. Ph. red hot, green cold.

*With Soda.*—O. F. Dark yellow hot, opaque and light yellow cold. R. F. Opaque and yellowish-green cold.

*In tube with  $KHSO_4$ .*—Dark violet hot, greenish cold.

#### INTERFERING ELEMENTS.

*Manganese.*—The soda bead in O. F. will be bright yellowish-green.

#### COBALT, Co.

*On Coal, R. F.*—The oxide becomes magnetic metal. The solution in HCl will be rose-red but on evaporation will be blue.

*With Borax or S. Ph.*—Pure blue in either flame.

#### INTERFERING ELEMENTS.

*Arsenic, Sulphur, or Selenium.*—Roast and scorify with successive additions of borax. If other elements are present which color strongly the glasses will be in order given: Yellow (iron), green (iron and cobalt), blue (cobalt), reddish-brown (nickel), green (nickel and copper), blue (copper). Metallic lead or gold may be used to collect the metals as described, p. 201.

#### COLUMBIUM, Cb.

Heat strongly on coal with borax, crush and dissolve in conc. HCl and add metallic tin. A bluish-gray color, disappearing on moderate dilution indicates Cb. Tungsten under same conditions remains blue.

#### COPPER, Cu.

*On Coal R. F.*—Formation of red malleable metal.

*Flame.\**—Emerald-green or azure-blue, according to compound. The azure-blue flame may be obtained:

(a) By moistening with HCl or aqua regia, drying gently in O. F. and heating strongly in R. F.

(b) By saturating S. Ph. bead with substance, adding common salt, and treating with blue flame.

*With Borax† or S. Ph.*—O. F. Green hot, blue or greenish-blue cold.

---

\* Sulphur, selenium and arsenic should be removed by roasting. Lead necessitates a gentle heat.

† By repeated slow oxidation and reduction, a borax bead becomes ruby red.

R. F. Greenish or colorless hot, opaque and brownish-red cold. With tin on coal this reaction is more delicate.

#### INTERFERING ELEMENTS.

*General Method.\**—Roast thoroughly, treat with borax on coal in strong R. F., and

*If Button Forms.*—Separate the button from the slag, remove any lead from it by O. F., and make either S. Ph. or flame test upon residual button.

*If no Visible Button Forms.*—Add test lead to the borax fusion, continue the reduction, separate the button and treat as in next test. (Lead Alloy.)

*Lead or Bismuth Alloys.*—Treat with frequently changed boracic acid in strong R. F., noting the appearance of slag and residual button.

*Trace.*—A red spot in the slag.

*Over One Per Cent.*—The residual button will be bluish-green when melted, will dissolve in the slag and color it red upon application of the O. F., or may be removed from the slag and be submitted to either the S. Ph. or the flame test.

#### FLUORINE, F.

*Etching Test.*—If fluorine is released it will corrode glass in cloudy patches, and in presence of silica there will be a deposit on the glass. According to the refractoriness of the compound the fluorine may be released:

(a) In closed tube by heat.

(b) In closed tube by heat and  $\text{KHSO}_4$ .

(c) In open tube by heat and glass of S. Ph.

*With Conc.  $\text{H}_2\text{SO}_4$  and  $\text{SiO}_2$ .*—If heated and the fumes condensed by a drop of water upon a platinum wire, a film of silicic acid will form upon the water.

#### IODINE, I.

*With S. Ph. Saturated with  $\text{CuO}$ .*—Treated at the tip of the blue flame the bead is surrounded by an intense emerald-green flame.

*In Matrass with  $\text{KHSO}_4$ .*—Violet choking vapor and brown sublimate.

---

\* Oxides, sulphides, sulphates are best reduced by a mixture of soda and borax.



*In Open Tube with Equal Parts Bismuth Oxide, Sulphur and Soda.*—A brick-red sublimate.

*With Starch Paper.*—The vapor turns the paper dark purple.

#### INTERFERING ELEMENTS.

*Silver.*—The iodide melts in  $\text{KHSO}_4$  to a dark red globule, yellow on cooling, and unchanged by sunlight.

#### IRON, Fe.

*On Coal.*—R. F. Many compounds become magnetic. Soda assists the reaction.

*With Borax.\**—O. F. Yellow to red hot, colorless to yellow cold.

R. F. Bottle-green. With tin on coal, vitriol-green.

*With S. Ph.*—O. F. Yellow to red hot, greenish while cooling, colorless to yellow cold.

R. F. Red hot and cold, greenish while cooling.

*State of the Iron.*—A borax bead blue from  $\text{CuO}$  is made red by  $\text{FeO}$ , and greenish by  $\text{Fe}_2\text{O}_3$ .

#### INTERFERING ELEMENTS.

*Chromium.*—Fuse with nitrate and carbonate of soda on platinum, dissolve in water and test residue for iron.

*Cobalt.*—By dilution the blue of cobalt in borax may often be lost before the yellow of iron.

*Copper.*—May be removed from borax bead by fusion with lead on coal in R. F.

*Manganese.*—(a) May be faded from borax bead by treatment with tin on coal in R. F.

(b) May be faded from S. Ph. bead by R. F.

*Nickel.*—May be faded from borax bead by R. F.

*Tungsten or Titanium.*—The S. Ph. bead in R. F. will be reddish-brown instead of blue or violet.

*Uranium.*—As with chromium.

*Alloys, Sulphides, Arsenides, etc.*—Roast, treat with borax on coal in R. F., then treat borax in R. F. to remove reducible metals.

#### LEAD, Pb.

*On Coal.†*—In either flame is reduced to malleable metal and

\* A slight yellow color can only be attributed to iron, when there is no decided color produced by either flame in highly charged beads of borax and S. Ph.

† The phosphate yields no coat without the aid of a flux.

yields, near the assay, a dark lemon-yellow coat, sulphur-yellow cold and bluish-white at border.

*With Bismuth Flux:*

*On Plaster.*—Chrome-yellow coat, blackened by  $(\text{NH}_4)_2\text{S}$ .

*On Coal.*—Volatile yellow coat, darker hot.

*Flame.*—Azure-blue.

*With Nitric Acid and Potassic Iodide.*—Place a drop of 1-1  $\text{HNO}_3$  on the sample. On this drop sprinkle a little powdered KI. "If Pb is present a vivid yellow color soon appears."

#### INTERFERING ELEMENTS.

*Antimony.*—Treat on coal with boracic acid, and treat the resulting slag on plaster with bismuth flux.

*Arsenic Sulphide.*—Remove by gentle O. F.

*Cadmium.*—Remove by R. F.

*Bismuth.*—Usually the bismuth flux tests on plaster are sufficient. In addition the lead coat should color the R. F. blue.

#### LITHIUM, Li.

*Flame.*—Crimson, best obtained by gently heating near the wick.

#### INTERFERING ELEMENTS.

*Sodium, (a)* Use a gentle flame and heat near the wick. *(b)* Fuse on platinum wire with barium chloride in O. F. The flame will be first strong yellow, then green, and lastly, crimson.

*Calcium or Strontium.*—As these elements do not color the flame in the presence of barium chloride, the above test will answer.

*Silicon.*—Make into a paste with boracic acid flux and water, and fuse in the blue flame. Just after the flux fuses the red flame will appear.

#### MAGNESIUM, Mg.

*On Coal with Soda.*—Insoluble, and not absorbed by the coal.

*With Borax or S. Ph.*—Clear and colorless can be flamed opaque-white.

*With Cobalt Solution.\**—The substance moistened with the solution and heated *strongly* upon coal becomes pale pink or flesh color.

#### MANGANESE, Mn.

*With Borax or S. Ph.†*—O. F. Amethystine hot, reddens on cool-

\* With silicates this reaction is of use only in the absence of coloring oxides. The phosphate, arsenate and borate become violet-red.

† The colors are more intense with borax than with S. Ph.

ing. With much, is black and opaque. If a hot bead is touched to a crystal of sodium nitrate an amethystine or rose-colored froth is formed.

R. F. Colorless or with black spots.

*With Soda.*—O. F. Bluish-green and opaque when cold. Sodium nitrate assists the reaction.

#### INTERFERING ELEMENTS.

*Chromium.*—The soda bead in O. F. will be bright yellowish-green instead of bluish-green.

*Silicon.*—Dissolve in borax, then make soda fusion.

#### MERCURY, Hg.

*With Bismuth Flux:*

*On Plaster.*—Volatile yellow and scarlet coat. If too strongly heated the coat is black and yellow.

*On Coal.*—Faint yellow coat at a distance.

*Closed Tube with Dry Soda or with Litharge.\**—Mirror-like sublimate, which may be collected in globules.

#### MOLYBDENUM, Mo.

*With Conc.  $H_2SO_4$ .*—The powder is moistened with the acid and evaporated almost to dryness on porcelain. On cooling, dark blue spots are formed.

*Flame.*—Yellowish-green.

*With Borax.*—O. F. Yellow hot, colorless cold.

R. F. Brown to black and opaque.

*With S. Ph.*—O. F. Yellowish-green hot, colorless cold.

R. F. Emerald-green.

The bead, if saturated and crushed, will either stain damp unglazed paper brown to blue according to amount present or if dissolved in very dilute *cold* HCl with little metallic tin, will yield a blue solution which becomes brown on heating.

---

\* Gold-leaf is whitened by the slightest trace of vapor of mercury.

**NICKEL, Ni.**

*With Dimethylglyoxime.*—To any solution containing nickel, add ammonia, filter off precipitate and to filtrate add a few drops of one per cent. solution of reagent in alcohol. A crimson color and precipitate results.

*On Coal.*—R. F. The oxide becomes magnetic.

*With Borax.*—O. F. Violet hot, pale reddish-brown cold.

R. F. Cloudy and finally clear and colorless.

*With S. Ph.*—O. F. Red hot, yellow cold

R. F. Red hot, yellow cold. On coal with tin becomes colorless.

**INTERFERING ELEMENTS.**

If the dimethyl reagent is available it will be satisfactory. If not available the methods of scorifying mentioned under cobalt may be used.

*Arsenic.*—Roast thoroughly, treat with borax in R. F. as long as it shows color, treat residual button with S. Ph. in O. F.

*Alloys.*—Roast and melt with frequently changed borax in R. F. adding a little lead if infusible. When the borax is no longer colored, treat residual button with S. Ph. in O. F.

**NITRIC ACID, HNO<sub>3</sub>.**

*In Closed Tube with KHSO<sub>4</sub>.*—Brown fumes with characteristic odor. The fumes will turn ferrous sulphate paper brown.

**PHOSPHORUS, P.**

*With Ammonic Molybdate.*—This is the surest test. See page 204.

*Flame.*—Greenish-blue, momentary. Improved by first dipping the wire in concentrated H<sub>2</sub>SO<sub>4</sub>.

*With Magnesium.*—Build a pyramid of the powder on charcoal around a half inch of magnesium ribbon and ignite by touching with the flame; then place in water. The gas evolved will have an odor of putrid fish.

**POTASSIUM, K.**

*Flame.*—Violet, except borates and phosphates.

## INTERFERING ELEMENTS.

*Sodium*.—(a) The flame, through blue glass, will be violet or blue.

(b) A bead of borax and a little boracic acid, made brown by nickel, will become blue on addition of a potassium compound.

*Lithium*.—The flame, through green glass, will be bluish-green.

*Sodium, Lithium, Strontium, Calcium*. Use color screen, p. 165.

## SELENIUM, Se.

*On Coal, R. F. or in Closed Tube*.—Disagreeable horse-radish odor, brown fumes, and a volatile steel-gray coat with a red border (or dark red sublimate).

*On Coal with Soda*.—Thoroughly fuse in R. F., place on bright silver, moisten, crush, and let stand. The silver will be blackened.

SILICA, SiO<sub>2</sub>.

Satisfactory test needed; possibly the best are as follows:

*Fuse with equal parts Na<sub>2</sub>CO<sub>3</sub>, K<sub>2</sub>CO<sub>3</sub>* on platinum. Dissolve fused material in dilute HCl and partially evaporate. A jelly proves SiO<sub>2</sub>.

*With Conc. H<sub>2</sub>SO<sub>4</sub> and CaF<sub>2</sub>*.—If placed in a lead cup and the fumes condensed by a drop of water upon a platinum wire a jelly forms on the water.

*With S. Ph.*—Insoluble. Silicates usually leave a translucent mass of the shape of the original fragment. If not decomposed by S. Ph., dissolve in borax nearly to saturation, add S. Ph., and re-heat for a moment. The bead will become milky or opaque white.

## SILVER, Ag.

*On Coal*.—Silver minerals heated on charcoal are decomposed and a malleable "button" results which if dissolved in a drop of nitric acid will yield a white curd-like precipitate on addition of a drop of hydrochloric acid.

*Cupellation*.—The only test for a silver ore as distinct from a rich silver mineral. See under Silver Minerals.

**SODIUM, Na.**

*Flame.*—Strong reddish-yellow.

**STRONTIUM, Sr.**

*On Coal with Soda.*—Insoluble, absorbed by the coal.

*Flame.*—Intense crimson, improved by moistening with HCl.

*With Borax or S. Ph.*—Clear and colorless; can be flamed opaque.

**INTERFERING ELEMENTS.**

*Barium.*—The red flame may show upon first introduction of the sample into the flame, but it is afterward turned brownish-yellow.

*Lithium.*—Fuse with barium chloride, by which the lithium flame is unchanged.

**SULPHUR, S.**

*On Coal with Soda and a Little Borax.*—Thoroughly fuse in the R. F., and either :

- (a) Place on bright silver, moisten, crush and let stand. The silver will become brown to black. Or,
- (b) Heat with dilute HCl (sometimes with powdered zinc); the odor of  $H_2S$  will be observed.

*In Open Tube.*—Suffocating fumes. Some sulphates are unaffected.

*In Closed Tube.*—May have sublimate red when hot, yellow cold, or sublimate of undecomposed sulphide, or the substance may be unaffected.

*With Soda and Silica* (equal parts).—A yellow or red bead.

*To Determine Whether Sulphide or Sulphate.*—Fuse with soda on platinum foil. The sulphide only will stain silver.

**TELLURIUM, Te.**

*On Coal.*—Volatile white coat with red or yellow border. If the fumes are caught on porcelain, the resulting gray or brown film may be turned crimson when moistened with conc.  $H_2SO_4$ , and gently heated.

*With Hot Conc.  $H_2SO_4$ .*—Rich powdered material placed on a white porcelain plate in contact with a drop of the hot acid assumes a violet color.

### TIN, Sn.

*On Coal Alone or with Soda or Sulphur.*—R. F. Strongly heated forms yellow coat, white cold. If moistened with cobalt solution and strongly heated the coat becomes bluish green.

*With Metallic Zn and HCl.*—A fragment of cassiterite, placed in contact with metallic Zn in dilute HCl, becomes coated with metallic tin.

#### INTERFERING ELEMENTS.

*Lead or Bismuth (Alloys).*—It is fair proof of tin if such an alloy oxidizes rapidly with sprouting and cannot be kept fused.

*Zinc.*—On coal with soda, borax and charcoal in R. F. the tin will be reduced, the zinc volatilized; the tin may then be washed from the fused mass.

### TITANIUM, Ti.

*With S. Ph.*—O. F. Colorless to yellow hot, colorless cold, R. F. After careful solution in the O. F. the bead may be made violet by strong reduction.

*S. Ph. Bead in Acids.*—If after the careful solution in O. F. the bead is dissolved by boiling in a weak (1 : 3) solution of sulphuric acid with a little nitric acid, the addition of a few drops of hydrogen peroxide will produce a deep yellow color.

#### INTERFERING ELEMENTS.

*Iron.*—The S. Ph. bead in R. F. is yellow hot, brownish-red cold.

### TUNGSTEN, W.

*With S. Ph.*—O. F. Clear and colorless.

R. F. Greenish hot, blue cold. On long blowing or with tin on coal, becomes dark green.

Either bead crushed and dissolved in conc. HCl with metallic tin will yield a deep blue solution, not destroyed by even considerable dilution and on evaporation to syrup give a purple permanganate color.

#### INTERFERING ELEMENTS.

*Iron.*—The S. Ph. in R. F. is yellow hot, blood-red cold.

## URANIUM, U.

*Nitric Acid Solution.*—Dissolve in dilute  $\text{HNO}_3$ , make alkaline with  $\text{Na}_2\text{CO}_3$ , filter and to filtrate <sup>(after acidifying with  $\text{HCl}$  and boiling to expel  $\text{CO}_2$ )</sup> add solution of  $\text{NaOH}$ , precipitating yellow sodium uranate.

*With S. Ph.*—O. F. Yellow hot, yellowish-green cold.

R. F. emerald-green.

*Photographic Plate.\**—Wrap in the dark a photographic plate in two thicknesses of black paper. On the paper place a key. Just above the key suspend 2 or 3 oz. of the ore. Place the whole in light-tight box. Avoid pressure of ore on key and plate.

After 3 or 4 days develop in the usual way.

*Electroscope.*—A test dependent upon the power of radium to discharge an electroscope may be made quantitative. A suitable electroscope† consists of two compartments; one above containing a suspended gold leaf in front of which is attached a reading microscope, and one below in which the ore to be tested is placed. Usually the leaf is charged by means of a piece of vulcanite rubbed on the sleeve of the coat, the charge causing the leaf to rise; then the natural leak of electricity is noted on the scale and calculated as a certain number of divisions per minute. The ore is then placed in the compartment below and the leak of the leaf noted as before. For example:

Natural leak of instrument = 0.5 divisions per minute

Fall of leaf with 3 per cent.  $\text{U}_3\text{O}_8$  ore = 48.5 " " "

Fall of leaf with ore tested = 36.5 " " "

Deducting the natural leak from each

$\text{U}_3\text{O}_8$  in standard ore:

$\text{U}_3\text{O}_8$  in ore tested = 48 : 36

$\text{U}_3\text{O}_8$  in ore tested =  $\frac{36 \times 3}{48} = 2.2$  per cent.

## INTERFERING ELEMENTS.

*Iron.*—With S. Ph. in R. F. is green hot, red cold.

\* Thorium has a decomposition product, mesothorium, which also is radio-active.

† Prospector's Device, *E. & M. J.*, May 16, 1914, p. 996 or Bulletin 70, Bureau of Mines, p. 26.



**VANADIUM, V.**

*Hydrochloric Acid Solution.*—Boiled with conc. HCl gives a brownish-red solution which is decolorized by a few drops of water and regains its color with a few drops of peroxide of hydrogen:

(Patronite needs separate roasting and roscoelite a previous fusion with sodium carbonate.)

*With S. Ph.*—O. F. Dark yellow hot, light yellow cold.

R. F. Brown hot, emerald-green cold.

**ZINC, Zn.**

*On Coal.*—R. F. Yellow coat, white when cold. If moistened with cobalt solution and strongly heated the coat becomes bright green.

It is best to moisten the coal, in front of the assay, with the solution, and blow a strong R. F. upon the assay.

**INTERFERING ELEMENTS.**

*Antimony.*—Remove by strong O. F., or by heating with sulphur in closed tube.

*Cadmium Lead or Bismuth.*—The combined coats will not prevent the cobalt solution test.

*Tin.*—The coats heated in an open tube, with charcoal dust by the O. F., may yield white sublimate of zinc.

## CHAPTER XIV.

### SCHEMES FOR QUALITATIVE BLOWPIPE ANALYSIS.

**TEST I.\*** — Heat a portion gently with O. F. upon charcoal or a plaster tablet which has been blackened in the lamp flame.

**As.** — White very volatile crystalline coat, white fumes having garlic odor and invisible near assay, best on plaster.

The coat disappears before R. F., tingeing it pale blue and evolving the characteristic garlic odor.

**CONFIRMATION As.** — The coating may be scraped off together with a little charcoal and if heated in closed tube should yield an arsenic mirror; or it may be dissolved in solution of KOH, placed in a test-tube, a small piece of sodium amalgam added, and the tube covered with a piece of filter paper moistened with a *slightly* acid solution of  $\text{AgNO}_3$ . The paper will be stained black by the  $\text{AsH}_3$  evolved.

**Sb.** — White fumes and white pulverulent volatile coat, best on charcoal.

A good distinguishing feature between As and Sb is as follows: They both usually continue to give off fumes after removal of the flame, but while still hot the  $\text{As}_2\text{O}_3$  fumes are not visible within one-half inch of assay, while  $\text{Sb}_2\text{O}_3$  fumes appear to come immediately from the mass.

**CONFIRMATION Sb.** — The coating disappears before R. F., tingeing it a pale yellow-green, or, if scraped together, dissolved in S. Ph. and *just* fused on charcoal in contact with tin it will form a gray or black opaque bead.

If the coating be scraped off and dissolved in tartaric acid + HCl, and the solution placed in a platinum capsule with a piece of zinc, Sb, if present, will give a black adherent stain. This may be confirmed by washing the stain with water, then dissolving it in a few drops of hot tartaric acid plus a drop or two of HCl; on adding  $\text{H}_2\text{S}$ , an orange precipitate proves  $\text{Sb}_2\text{S}_3$ .

Most antimony minerals leave a white residue when treated with concentrated nitric acid. If this residue is washed with water, dissolved in HCl and  $\text{H}_2\text{S}$  added, an orange precipitate of  $\text{Sb}_2\text{S}_3$  will be formed.

**TEST II.** — Mix some of the powdered substance with metallic sodium† by means of a knife blade, ignite carefully on charcoal and heat residue with blowpipe flame to obtain coatings or to fuse together any metallic particles.‡ Or mix a portion with soda and

\* Test I. may also yield white coating of chlorides or lead sulphate, or of Se or Te, non-volatile coatings of Sn or Zn near the assay, yellow hot and white cold; yellow coatings of Pb or Bi; crystalline yellow and white coating of Mo; and deep brown coating of Cd. All of these will be detected with greater certainty by later tests.

† Test II. may also yield white coats from Pb, Bi or alkalis, yellow coats from Pb or Bi, brown or red coats from Cu or Mo, and the ash of the coal may be white or red.

‡ Until perfectly familiar with metallic sodium reaction always read the precaution on page 92.

a little borax and heat strongly upon charcoal with R. F. for three or four minutes.

*A. Volatile fumes or coating on charcoal.*

**As.**—Garlic odor, white fumes and a white volatile coat.

**Sb.**—White fumes and a white volatile coat.

**Cd.**—Dark brown volatile coat, sometimes shading to greenish-yellow and usually surrounded by a variegated coloration resembling the colors of peacock feathers.

**CONFIRMATION Cd.**—The coat forms at first heating, and, if mixed with  $\text{Na}_2\text{S}_2\text{O}_3$  and fused in a borax bead, will form a bright yellow mass of CdS.

**Zn.**—White not easily volatile coat, yellow when hot.

**Sn.**—White non-volatile coat close to assay, yellow while hot and usually small in amount.

**CONFIRMATION Zn and Sn.**—If any coat forms, moisten it with cobalt solution and blow a strong blue flame on the substance. The coatings from other elements will not prevent the cobalt coloration. The zinc coat is made bright yellowish-green. The tin coat becomes bluish-green.

*B. Residue left on charcoal.*

**Crush, pulverize and examine the residue for**

1. Magnetic particles; 2. Metallic buttons; 3. On moist silver coin.

1. Collect any magnetic particles with the magnet; dissolve some of the magnetic particles in a borax bead with the O. F. Try also effect of R. F.

**Fe.**—The bead is: O. F. hot, yellow to red; O. F. cold, colorless to yellow; R. F. cold, bottle-green.

**CONFIRMATION Fe.**—The magnetic particles yield with  $\text{HNO}_3$ , a brown solution from which, after evaporating excess of acid,  $\text{K}_4\text{FeCy}_6$  throws down a blue precipitate.

**Ni.**—The bead is: O. F. hot, intense violet; O. F. cold, pale brown; R. F. cold, colorless.

**CONFIRMATION Ni.**—If the excess of acid is driven off by evaporation, KCy added in excess, and the solution then made strongly alkaline with KOH, two or three drops of pure bromine will give a black precipitate of  $\text{Ni}_2(\text{OH})_6$ .

**Co.**—The bead is: O. F. and R. F. hot or cold, a deep pure blue; if greenish when hot, probably Fe or Ni is also present.

**CONFIRMATION Co.**—The magnetic particles yield with  $\text{HNO}_3$ , a red-rose solution which becomes blue on evaporation.

**2. Examine residue for metallic buttons and observe if they are malleable or not.\***

**Ag.** — Silver white malleable button.

**CONFIRMATION Ag.** — Dissolve button in dilute  $\text{HNO}_3$ , and add a drop of  $\text{HCl}$ . A white precipitate, soluble in  $\text{NH}_4\text{OH}$  is obtained.

**Pb.** — Lead gray malleable button.

**CONFIRMATION Pb.** — With bismuth flux on charcoal gives yellow coating.

**Sn.** — White malleable button.

**CONFIRMATION Sn.** — Heated in O. F. on charcoal gives a non-volatile coating, yellow hot and white cold. Decomposed in conc.  $\text{HNO}_3$  with white residue of meta-stannic acid.

**Cu.** — Reddish malleable button.

**CONFIRMATION Cu.** — Dissolves in  $\text{HNO}_3$  to a green solution rendered intense blue when neutralized with  $\text{NH}_4\text{OH}$ .

**Au.** — Yellow malleable button.

**CONFIRMATION Au.** — Insoluble in  $\text{HNO}_3$  or  $\text{HCl}$  alone, but dissolved by mixed acids.

**Bi.** — Reddish white brittle button.

**CONFIRMATION Bi.** — Heat with bismuth flux.

**Sb.** — White brittle button, yielding white coating before the blowpipe.

**3. Dig up some of the charcoal beneath assay, place upon a bright silver surface; moisten with water and let stand.**

**S, Se, Te.**—The bright silver is stained black or dark-brown, and unless the horseradish odor of Se or the brown coatings of Se and Te with bismuth flux have been already obtained, this stain will prove sulphur.

**CONFIRMATIONS S.**—The soda fusion will evolve  $\text{H}_2\text{S}$  when moistened with  $\text{HCl}$ . By holding in the gas a piece of filter paper moistened with a drop or two of lead acetate (test is made more sensitive by adding a drop of ammonia to the acetate), the paper will be stained black.

**CONFIRMATION Se.**—Characteristic disagreeable horseradish odor during fusion.

**CONFIRMATIONS Te.**—If a little of the original substance is dropped into boiling concentrated  $\text{H}_2\text{SO}_4$ , a deep violet color is produced; this disappears on further heating.

The quite cold soda fusion added to hot water produces a purple-red solution.

**TEST III.**—Mix a portion of the substance with more than an equal volume of bismuth flux,† and heat gently upon a plaster tablet with the oxidizing flame.

\* A white malleable button of zinc is sometimes obtained but not if reduction was made by soda. It is easily soluble in cold dilute hydrochloric acid with effervescence.

† Formed by grinding together 1 part  $\text{KI}$ , 1 part  $\text{KHSO}_4$ , 2 parts  $\text{S}$ .

**Pb.**—Chrome-yellow coat, darker hot, often covering the entire tablet.

**CONFIRMATION Pb.**—If the test is made on charcoal, the coat is greenish-yellow, brown near the assay.

**Hg.**—Gently heated, bright scarlet coat, very volatile, and with yellow fringe; but if quickly heated, the coat formed is pale yellow and black.

**CONFIRMATION Hg.**—If the substance is heated gently in a closed tube or matrass with dry soda or litharge, a mirror-like sublimate will form, which may be collected into little globules of Hg by rubbing with a match end. The test with bismuth flux on charcoal yields only a faint yellow coat.

**Bi.**—Bright chocolate-brown coat, with sometimes a reddish fringe.

**CONFIRMATIONS Bi.**—The coat is turned orange-yellow, then cherry-red, by fumes of  $\text{NH}_3$ , which may conveniently be produced by heating a few crystals of S. Ph. on the assay. The test with bismuth flux on charcoal yields a bright-red band, with sometimes an inner fringe of yellow.

**Sb.**—Orange to peach-red coat, very dark when hot.

**CONFIRMATION Sb.**—The coat becomes orange when moistened with  $(\text{NH}_4)_2\text{S}$ .

Test III. may yield colored sublimates with large amounts of certain other elements, and on smoked plaster certain white sublimates are obtainable. In all cases the elements are detected with greater certainty by other tests, but for convenience they are here summarized: Sn, brownish-orange; As, reddish-orange; Se, reddish-brown; Te, purplish-brown, with deep brown border; Mo, deep ultramarine blue; Cu, Cd, Zn, white on smoked plaster.

**TEST IV.**—Dissolve substance in salt of phosphorus in O. F. so long as bead remains clear on cooling. Treat then for three or four minutes in a strong R. F. to remove volatile compounds. Note the colors hot and cold, then re-oxidize and note colors hot and cold.

**Fe, Ti, Mo, W.**—The bead in O. F. cold is COLORLESS or very FAINT YELLOW.

**CONFIRMATION Fe.**—The bead in its previous treatment should have been O. F. hot, yellow to red; O. F. cold, colorless; R. F. cold, red.

**CONFIRMATION Ti.**—The bead is reduced on charcoal with tin, pulverized and dissolved in  $\frac{1}{4}$  HCl with a little metallic tin. The reduced bead is violet, the solution is violet and turbid.

**CONFIRMATIONS Mo.**—Tested as above on charcoal with tin, etc., the reduced bead is green, the solution is dark brown. Heat a little of the substance on platinum foil with a few drops of conc.  $\text{HNO}_3$ , heat until excess of  $\text{HNO}_3$  has all volatilized, then add

few drops of strong  $\text{H}_2\text{SO}_4$  and heat until copious fumes are evolved; cool, and breathe upon the cooled mass; an ultramarine blue = Mo.

**CONFIRMATION W.**—Tested on charcoal with tin, etc., as above, the reduced bead is green, the solution is deep blue.

**Ur, V, Ni.\***—The bead in O. F. cold, is colored YELLOW OR GREENISH-YELLOW.

**CONFIRMATION U.**—The bead in R. F. is dull green, hot; fine green, cold. Make a  $\text{Na}_2\text{CO}_3$  fusion, dissolve in HCl or  $\text{H}_2\text{SO}_4$ , add a few drops of  $\text{H}_2\text{S}$  water, and if it gives any precipitate, add it in excess and filter; to filtrate add a few drops of  $\text{HNO}_3$  and boil, then add  $\text{NH}_4\text{OH}$  to alkaline reaction, filter, wash precipitate with ammonia water, and then treat precipitate with a concentrated solution of  $(\text{NH}_4)_2\text{CO}_3 + \text{NH}_4\text{OH}$ , filter, acidify filtrate with HCl, and add  $\text{K}_4\text{FeCy}_6$ . Brown ppt. = Ur.

**CONFIRMATION V.**—In R. F. the bead will be brownish hot, fine green cold. Fuse substance with  $\text{Na}_2\text{CO}_3$  in O. F., and dissolve fusion in a few drops of dilute  $\text{H}_2\text{SO}_4$  or HCl, add a piece of zinc and warm; blue color changing to green and finally violet = V.

**CONFIRMATION Ni.**—A borax bead in O. F. will be intense violet, and in R. F. will be reddish hot, yellow cold.

**Mn.**—The bead in O. F., cold, is colored VIOLET; if touched while hot to a crystal of nitre, it is made deep permanganate color.

**CONFIRMATION Mn.**—Fused on platinum wire in O. F., with a paste of soda, and nitre, manganese yields an opaque bluish-green bead.

**Cr.**—The bead in O. F., cold, is colored GREEN.

\* If the absence of Ni is not proved, or Co obscures the tests, dissolve the substance in borax on charcoal to saturation, and treat for five minutes in hot R. F.

If a visible button results, separate it from the borax, and treat with S. Ph. in the O. F., replacing the S. Ph. when a color is obtained.

If no visible button results, add either a small gold button or a few grains of test lead. Continue the reduction, and, if lead has been used, scorify the button with frequently changed boracic acid to small size, stopping the instant the boracic acid is colored by Co, Ni, or Cu, blue, yellow, or red, respectively.

Complete the removal of lead by O. F. on coal, and treat as below.

Treat the gold alloy, or the residual button from the lead alloy, on coal, with frequently changed S. Ph., in strong O. F.

The metals which have united with the gold or lead, will be successively oxidized and their oxides will color the S. Ph. in the following order:

Co.—Blue, hot; blue, cold. May stay in the slag.

Ni.—Brown, hot; yellow, cold. May give green with Co or Cu.

Cu.—Green, hot; blue, cold. Made opaque red by tin and R. F.

The slag should contain the more easily oxidizable metals, and be free from Cu, Ni, and Ag. Test a portion with S. Ph. and tin to prove absence of Cu. If present, it must be removed by further reduction with lead. Pulverize the slags and dissolve a portion in S. Ph., and examine by Test V.

There may be a green bead from admixture of a blue and a yellow. If Cr is not proved, examine in such a case for Ur, V, Cr, etc., with unusual care.

**CONFIRMATION Cr.**—If the substance is fused on platinum wire in the O.F. with a paste of soda and nitre, an opaque yellow bead is produced; and if the soda bead is dissolved in water, filtered, acidified with acetic acid, and a drop or two of lead acetate added, a yellow precipitate will be formed.

**Co, Cu.**—The bead in O. F., cold, is colored BLUE.

**CONFIRMATION Co.**—The bead is deep blue, hot and cold, in both flames.

**CONFIRMATION Cu.**—The bead is green, hot, greenish-blue, cold, and on fusion with tin on coal becomes opaque brownish-red.

With larger percentage of copper, the substance will yield a mixed azure-blue and green flame on heating with HCl.

**SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, SnO<sub>2</sub>.**—The saturated bead contains an appreciable amount of INSOLUBLE MATERIAL, in the form of a *translucent* cloud, jelly-like mass, or skeleton form of the original material.

**CONFIRMATION SiO<sub>2</sub>.**—Mix the *dry* substance with a little *dry* calcium fluoride free from SiO<sub>2</sub>, place in platinum dish, add conc. H<sub>2</sub>SO<sub>4</sub> and heat gently, hold in fumes given off, a drop of water in loop of platinum wire; SiO<sub>2</sub> will be separated on coming in contact with the water and form a jelly-like mass.

Silica or silicates fused with soda unite with noticeable effervescence.

**CONFIRMATION Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, SnO<sub>2</sub>, SiO<sub>2</sub>.**—If infusible, moisten the pulverized mineral with dilute cobalt nitrate solution and heat strongly.

Al<sub>2</sub>O<sub>3</sub>.—Beautiful bright blue.

TiO<sub>2</sub>.—Yellowish green.

SnO<sub>2</sub>.—Bluish green.

SiO<sub>2</sub>.—Faint blue; deep blue, if fusible.

There may also be blues from fusible phosphates and borates, greens from oxides of Zn, Sb, violet from Zr, various indefinite browns and grays, and a very characteristic pale pink or flesh color from Mg.

**CONFIRMATION SnO<sub>2</sub>.**—Treat the finely pulverized mineral with Zn and HCl in contact with platinum. Dissolve any reduced metal in HCl and test with HgCl<sub>2</sub>. There will be white or gray ppt.

**Ba, Ca, Sr, Mg.**—The saturated bead is WHITE and OPAQUE and the nearly saturated bead can be flamed white and opaque.

**CONFIRMATION Ba, Ca, Sr.**—Moisten the flattened end of a clean platinum wire with dilute hydrochloric acid, dip it in the roasted substance, and heat strongly at the tip of the blue flame, and gently near the wick. Remoisten with the acid frequently.

Ba.—Yellowish-green flame, bluish-green through green glass.

Ca.—Yellowish-red (brick-red) flame, green through green glass.

Sr.—Scarlet-red flame, faint yellow through green glass.

There may also be produced Li, carmine-red flame, invisible through green glass.

**K**, rose-violet flame, reddish-violet through blue glass. **Na**, orange-yellow flame, invisible through blue glass. **Cu**, azure-blue and emerald green. **Se** and **As**, pale blue. **Mo**, **Sb**, **Te**, pale green.

**CONFIRMATION Mg**.—Moisten the roasted substance with cobalt solution, and heat strongly. The substance will be colored pale pink or flesh color, or violet if present as either arsenate or phosphate or borate.

**TEST V**.—Cupellation for silver and gold. Fuse one vol. of the roasted substance on charcoal with 1 vol. of borax glass, and 1 to 2 vols. of test lead in R. F. for about two minutes. Remove button and scorify it in R. F. with fresh borax, then place button on cupel and blow O. F. *across* it, using as strong blast and as little flame as are consistent with keeping the button melted. If the litharge is dark, or if the button freezes before brightening, or if it brightens but is not spherical, re-scorify it on charcoal with borax, add more test lead, and again cupel until there remains only a bright spherical button unaltered by further blowing.

**Ag**.—The button is white.

**Au**.—The button is yellow or white.

**CONFIRMATION Ag AND Au**.—Dissolve in a drop of  $\text{HNO}_3$ , and add a drop of  $\text{HCl}$ , producing a white curd-like precipitate. If gold is present there will be a residue insoluble in  $\text{HNO}_3$  which will become golden yellow on ignition.

**TEST VI**.—Heat substance in matrass with acid potassium sulphate.

**$\text{N}_2\text{O}_5$ , Br**.—Reddish brown vapor.

**CONFIRMATION  $\text{N}_2\text{O}_5$** .—The gas turns ferrous sulphate paper brown. Nitrates deflagrate violently when fused on charcoal.

**Cl**.—Colorless or yellowish green vapor, with odor of chlorine.

**I**.—Violet choking vapor.

**CONFIRMATION Br, Cl, I**.—Saturate a salt of phosphorus bead with  $\text{CuO}$ , add substance, and treat in O. F. Br, azure blue and emerald green flame. Cl, azure blue flame with a little green. I, emerald green flame.

Fuse with  $\text{Na}_2\text{CO}_3$ , pulverize and mix with  $\text{MnO}_2$ , and add a few drops of conc.  $\text{H}_2\text{SO}_4$  and heat. Cl, yellowish green gas that bleaches vegetable colors. Br, red fumes.

Fuse with  $\text{Na}_2\text{CO}_3$ , dissolve in water, make slightly acid with  $\text{H}_2\text{SO}_4$ , and add  $\text{Fe}_2(\text{SO}_4)_3$  (ferric alum may be used), and boil; I, violet fumes (turn starch paper blue).



**F.**—The glass of the matrass is corroded, and if  $\text{SiO}_2$  is present a film of  $\text{SiO}_2$  is often deposited on the glass.

**CONFIRMATION F.**—If the substance be mixed with silica and then heated with concentrated sulphuric acid, and the fumes caught on a drop of water held in a loop of platinum wire, gelatinous silica will form in the water.

**TEST VII.**—Heat the substance gently with water to remove air bubbles and then with dilute hydrochloric acid.

**$\text{CO}_2$ .**—Effervescence continuing after heat is removed.

$\text{H}_2\text{S}$ , Cl and H are sometimes evolved, but usually the odor will distinguish these.

**CONFIRMATION  $\text{CO}_2$ .**—If the gas is passed into lime water, a white cloud and ppt. will be produced.

**TEST VIII.**—Place a piece of Mg wire in a closed tube, and cover the wire with a mixture of soda and the substance. Heat till the mass takes fire, cool and add water.

**P.**—Evolution of phosphine, recognized by odor.

**CONFIRMATION P.**—Fuse a little of the substance, previously roasted if it contains As, with two or three parts  $\text{Na}_2\text{CO}_3$  and one of  $\text{NaNO}_3$  dissolve in  $\text{HNO}_3$ , and add excess of  $(\text{NH}_4)_2\text{MoO}_4$ ; yellow ppt. =  $\text{P}_2\text{O}_5$ . In presence of  $\text{SiO}_2$  it is well to confirm this ppt. by dissolving it in dilute  $\text{NH}_4\text{OH}$ , allowing it to stand for half an hour and filtering off any  $\text{SiO}_2$  that separates, then to filtrate adding magnesia mixture ( $\text{MgCl}_2 + \text{NH}_4\text{Cl} + \text{NH}_4\text{OH}$ ); white ppt. =  $\text{P}_2\text{O}_5$ .

Phosphates yield a pale momentary bluish green flame when moistened with concentrated  $\text{H}_2\text{SO}_4$  and treated at the tip of the blue flame.

**TEST IX.**—Make a paste of four parts  $\text{KHSO}_4$ , one part  $\text{CaF}_2$ , water and substance. Treat at tip of blue flame. Just after water is driven off the flame will be colored.

**B.**—Bright green.

**Li.**—Carmine.

**CONFIRMATION B.**—Heat some of the substance gently on platinum wire, then add a drop of concentrated  $\text{H}_2\text{SO}_4$ , heat very gently again, just enough to drive off excess of  $\text{H}_2\text{SO}_4$ , dip in glycerine, hold in flame until glycerine begins to burn, remove from flame, and the mass will continue burning with a green flame. Turmeric paper, moistened with an HCl solution containing boron and dried at  $100^\circ$ , is turned a reddish brown which ammonia blackens.

**TEST X.**—Make a paste of the powdered substance with strong HCl. Treat on platinum wire in the non-luminous flame of a Bunsen burner. Confirm results by the spectroscope as directed on page 87.

The color imparted to the flame is :

|            | <i>Alone.</i>                     | <i>Through blue glass.</i>        |
|------------|-----------------------------------|-----------------------------------|
| Na,        | Yellow.                           | Invisible or pale blue.           |
| K,         | Violet.                           | Reddish violet.                   |
| Na and K,  | Yellow.                           | Reddish violet.                   |
| Ba, Mo, B, | Yellowish green.                  | Bluish green.                     |
| Ca,        | Red.                              | Greenish gray.                    |
| Sr,        | Scarlet.                          | Violet.                           |
| Cu,        | { Azure blue,<br>Emerald green. } | { Azure blue.<br>Emerald green. } |

TEST XI. — Heat the substance in a closed tube.\*

H<sub>2</sub>O. — Moisture on the side of tube.

Hg. — Metallic mirror collecting in globules.

As. — Metallic mirror but no globules.

TEST XII.† — Treat the finely powdered substance in a test-tube with strong HCl. Observe the result, then boil.

**Effervescence.** — If the substance is non-metallic the gas given off will almost always be CO<sub>2</sub>, showing that the substance was a carbonate. H<sub>2</sub>S is easily recognized by its odor. Cl which is yellowish and very offensive would be given off only in a few cases by the action of some oxides on HCl.

**CONFIRMATION CO<sub>2</sub>.** — A drop of lime water on the end of a glass rod held in the gas after it has been passed through water to free it from HCl will be rendered turbid.

**CONFIRMATION H<sub>2</sub>S.** — A piece of filter paper moistened with lead acetate will be blackened if held in the gas.

**CONFIRMATION Cl.** — A piece of moistened red litmus paper held in the gas will be bleached.

**Gelatinous Residue.** — If a gelatinous residue forms after boiling away the larger part of the acid a silicate was present.

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\* Other sublimates may result as noted on page 94.

† Substitute for test VII. when convenient.

**SPECIAL SCHEME FOR DETECTION OF THOSE  
METALS WHICH WHEN PRESENT AS SILI-  
CATES USUALLY FAIL TO YIELD  
SATISFACTORY TESTS BEFORE  
THE BLOWPIPE.**

Remove the volatile constituents as thoroughly as possible by roasting, then heat gently in a platinum capsule, with HF and a few drops of concentrated  $H_2SO_4$  as long as fumes are given off; add a little more HF and  $H_2SO_4$ , and heat again in the same way. When fusion is quite cold, dissolve in cold water and filter.

**Filtrate a.**—Divide into four parts and test as follows:

1. Add a piece of Zn or Sn and a little HCl, and heat.

**Ti.**—A violet or blue solution.

**CONFIRMATIONS Ti.**—Nearly neutralize solution, and then add  $Na_2S_2O_8$ , and boil. White ppt. = Ti.

Or, make solution slightly alkaline, and then acidify slightly with HCl, and add  $Na_2HPO_4$ . White ppt. = Ti.

2. Add excess of KOH or NaOH, boil and filter, and to filtrate add excess of  $NH_4Cl$  and boil.

**Al.**—White precipitate.

Dissolve ppt., produced by the KOH or NaOH, in HCl, and add  $K_4FeCy_6$ .

**Fe.**—Blue precipitate.

3. Add HCl; then make alkaline with  $NH_4OH$  and add  $(NH_4)_2S$  +  $(NH_4)_2CO_3$  in slight excess, filter; to filtrate add  $Na_2HPO_4$ .

**Mg.**—White *crystalline* precipitate.

**CONFIRMATION Mg.**—If phosphates are present, this test would not be reliable for Mg. In such cases test a few drops of the solution with  $H_2S$ ; if it causes any precipitate, saturate the whole of the solution with it, filter, and to filtrate add a few drops of  $HNO_3$ , and boil to oxidize FeO, nearly neutralize with solution of  $Na_2CO_3$ . If iron is not present, add a few drops of  $Fe_2Cl_6$ , enough to give a red precipitate with the sodium acetate, then dilute and add excess of sodium acetate, and boil, filter, and to filtrate add  $NH_4OH$  +  $(NH_4)_2S$ , filter, to filtrate add  $Na_2HPO_4$ . White *crystalline* precipitate = Mg.

4. Add  $BaCl_2$  as long as it gives a precipitate, then  $Ba(OH)_2$ , to alkaline reaction, boil, filter, and to filtrate add  $(NH_4)_2CO_3$  and  $NH_4OH$  and heat, filter; evaporate filtrate to dryness and ignite to drive out  $NH_4$  salts. Test residue in flame for K and Na; dissolve residue in a few drops of water, filter if necessary, and then add solution of  $PtCl_4$  and alcohol.

**K.** — Yellow crystalline precipitate.

**CONFIRMATION Na, K.**—Mix 1 part of the silicate with 5-6 parts of precipitated  $\text{CaCO}_3$  and 1 part of  $\text{NH}_4\text{Cl}$ , heat to redness in platinum capsule for thirty minutes being careful to apply heat gently at first, digest sintered mass in hot water, and filter; to filtrate add  $(\text{NH}_4)_2\text{CO}_3$  and  $\text{NH}_4\text{OH}$ , heat and filter, evaporate filtrate to dryness and ignite gently until all ammonium salts are driven off, then determine Na and K as above.

**Residue a.**—Boil with strong solution of  $(\text{NH}_4)_2\text{SO}_4$  and filter.

**Filtrate b.**—Add a few drops of  $\text{H}_2\text{S}$  water; if any precipitate forms, saturate with  $\text{H}_2\text{S}$  and filter, and to filtrate add  $\text{NH}_4\text{OH}$  and  $(\text{NH}_4)_2\text{C}_2\text{O}_4$ .

**Ca.**—A white precipitate.

**Residue b.**—Moisten with concentrated  $\text{HCl}$  and try coloration of flame.

**Ba.**—Yellowish-green flame.

**Sr.**—Scarlet flame.

**CONFIRMATION Ba and Sr.**—Fuse residue b with two to three pts. of soda in a platinum capsule: treat fusion with boiling water, filter, reject filtrate, dissolve residue in acetic acid, add a few drops of  $\text{H}_2\text{S}$  water, if it gives any precipitate, saturate with  $\text{H}_2\text{S}$  and filter, and to filtrate add  $\text{K}_2\text{Cr}_2\text{O}_7$ . **Ba** = yellow precipitate. Filter, and to filtrate add  $\text{CaSO}_4$  warm and let stand. **Sr** = white precipitate.

## PART III.

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# MINERALOGY.

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## CHAPTER XV.

### DEFINITION AND PHYSICAL CHARACTERS OF MINERALS.

#### Definition of a Mineral.

The solid crust of the earth is composed principally of "minerals" each of which may be broadly defined as *a homogeneous substance of definite chemical composition, found ready-made in nature, and not directly a product of the life or the decay of an organism. Usually also it will possess a definite and characteristic crystalline structure.*

The definition excludes laboratory products and natural substances of organic origin.

*Laboratory products* and natural products may differ only in origin; for example, ice of the pond and the factory, natural and synthetic ruby. The line is arbitrarily drawn.

*Natural Substances of Organic Origin.*—Materials which have formed part of living organisms, coal, chalk, pearls, coral, shells, etc., are not minerals. If by natural agencies their organic structure is lost and a crystalline structure obtained or if their components recombine or combine with other elements, the new substances *are* minerals.

#### The Definite Chemical Composition.

The composition of a homogeneous mineral may vary by a series of replacements as explained under Isomorphism, p. 232, or in the case of "Gel Minerals," p. 235, may vary from taking up (adsorbing) other substances. In the former case a formula can be figured from the analysis, in the latter it is difficult or impossible.

#### The Characteristic Crystalline Structure.

This is a less constant attribute than was believed. While it is true that most minerals occur usually in the crystalline condi-

tion, it is a recognized fact that under proper conditions they occur in the amorphous condition either glassy or as a "gel mineral."

*The Crystalline Condition.*—A mineral is sometimes defined as a natural crystal, that is, possessing a crystalline structure and occurring either in crystals of characteristic shapes or in masses made up of many little crystals so crowded together that the shapes are not evident.

In the crystal and in each grain of the aggregation the crystalline structure will be shown by the constancy of the properties in parallel directions and their variation in directions not parallel.

*The Amorphous Condition.*—It has become recognized that quite a number of minerals have never been found in crystals and in the mass fail to show any regular crystalline structure. Such minerals are said to be *amorphous*. Usually they are "Gel minerals," products of weathering or hot springs action, which by their lack of uniform composition, generally amorphous structure and external appearance, suggest that they are products of colloidal origin. Opal is the best example.

The obsidians and the glassy inclusions in volcanic rocks are quickly cooled magma, that is, they are essentially minerals in solution.

### **The Study of Minerals or "Mineralogy."**

Mineralogy considers the one thousand or so definite minerals and the many thousands of varieties and doubtful species which constitute the solid crust of the earth. Its purpose is the study of all the qualities of these minerals; their chemical composition as revealed by analyses; their molecular structure as revealed by crystalline form and by physical tests, and their origin and mode of formation as revealed by associated minerals, the alterations which they undergo and their synthetic production.

In elementary work in mineralogy, especially in a technical course, the principal object is the acquisition of an "eye knowledge" of the common and commercially important minerals so that they may be recognized at sight or determined rapidly by a few simple tests. This knowledge can be acquired only by handling and testing many labelled and unlabelled specimens, and is best preceded by a thorough drill in the use of the blowpipe and a study of models and natural crystals. With this there should be gained a knowledge of their characters, economic uses and occurrence.

### **THE PHYSICAL CHARACTERS OF MINERALS.**

Minerals being for the most part in the crystalline condition, the geometric and optical characters described, pages 1 to 155, constitute their most important physical characters. The term is, however, very commonly used for the *remaining* physical characters described in the following pages and often subdivided into

groups, such as characters dependent on light, or cohesion or general characters, etc.

### LUSTRE.

THE lustre of a mineral is dependent upon its refractive power, its transparency and its structure. It may be called the *kind* of brilliancy or shine of the mineral.

METALLIC lustre is the lustre of metals. It is exhibited only by opaque minerals, and these, with the exception of the native metals, have a black or nearly black streak.

Some authorities \* make this very important, using the streak to confirm the lustre. It can, however, be used safely only in one direction. If the streak is essentially black the lustre is metallic, but the green streak of alabandite, the brownish red of specular hematite, the copper red of native copper, the pale greenish gray of molybdenite, do not prevent their lustre being metallic.

NON-METALLIC lustre is exhibited by all transparent or translucent minerals. It may be vitreous, adamantine, resinous, pearly, silky, greasy or waxy.

*Vitreous.* — The lustre of a fracture surface of glass or of a quartz crystal. Index of refraction  $n = 1.3$  to  $1.8$ .

*Adamantine.* — The almost metallic lustre of the uncut diamond, zircon or cerussite, exhibited by minerals of high index of refraction.  $n = 1.9$  to  $2.5$ .

*Resinous.* — The lustre of resin or sphalerite.

*Greasy.* — The lustre of oiled glass or *elæolite*.  $n = 1.7$  to  $1.9$ .

*Pearly.* — The lustre of the mother of pearl or of foliated talc. Common parallel to a very perfect cleavage.

*Silky.* — The lustre of silk or of satin spar, due to a fibrous structure.

*Dull.* — Without lustre or shine of any kind. Kaolin or chalk are good examples.

The prefix *sub*, as sub-metallic, sub-vitreous, is used to express an imperfect lustre of the kind.

The words splendent, shining, glistening, glimmering and dull are terms of *intensity* dependent on the quantity of light reflected.

Lustre should, when possible, be determined by a comparison with minerals of known lustre, and should always be observed on a fresh or unaltered surface.

The degree and kind of lustre are always the same on like faces

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\* Brush-Fenfield, *Determinative Mineralogy*, p. 226; Dana-Ford, p. 66.

of the crystal, but may be different on unlike faces, as in apophyllite, which has pearly basal pinacoid and vitreous prism faces.

### COLOR.

The surface colors are of two classes.

1. Colors dependent on the chemical constituents.
2. Colors dependent on physical causes.

#### Color Dependent on Chemical Composition.

Color is one of the least constant mineral characters, and varies with different specimens of the same species. It is frequently changed by a few hundredths of one per cent. of some organic or inorganic substance dissolved in the mineral, or by larger amounts of mechanically included foreign material.

In describing color the terms white, gray, brown, black, blue, green, yellow and red are used, with prefixes, which suggest the shade by the color of some familiar object. These need no explanation.

#### Color Due to Physical Causes.

If the observed surface color changes with the direction in which it is viewed it is due to interference of light.

*Play or Change of Colors.* — A succession of colors, varying with the direction the mineral is viewed, as in opal, labradorite, or diamond.

*Iridescence.* — Bands of prismatic colors, either from the interior of a mineral, as from a thin film of air between cleavages; or external and due to a thin coating or alteration.

*Tarnish.* — A surface which has been exposed to the air or to moisture is often of different color from the fresh fracture.

*Opalescence.* — A milky or pearly reflection, sometimes an effect of crystalline structure, at other times due to fibrous inclusions.

*Asterism.* — A star effect by reflected light, as in the ruby, or by transmitted light, as in some micas, and due to structure planes or symmetrically arranged inclusions.

### PHOSPHORESCENCE.

Many minerals, after being subjected to various outside influences, emit light which often persists for some time after removal of the exciting cause. Such emission of light is known as phosphorescence.



Phosphorescence may be induced by ordinary light, heat, friction, mechanical force or electrical stress but especially by the action of radium, polonium and actinium emanations, by X-rays and by ultra-violet light. In a particular specimen it may be induced by only one or by several of the agencies named. Phosphorescence is not always a characteristic of species but rather of the particular specimen or of species from a certain locality. On the other hand certain species are nearly always phosphorescent. Diamonds are generally strongly phosphorescent under radium emanations, but the degree of reaction varies with the individual specimen. They also phosphoresce under the influence of polonium, actinium, X-rays, ultra-violet rays and some rare specimens will glow in the dark even after exposure to sunlight or the light of the electric arc. Willamite from Franklin, New Jersey, and kunzite are strongly phosphorescent under the influence of radium, polonium, actinium and X-rays. Chlorophane, a variety of fluorite, phosphoresces at times by the simple heat of the hand, while fluorite itself may phosphoresce, fluoresce or do neither according to the specimen. All minerals from Borax Lake, California, phosphoresce under the influence of ultra-violet rays, which would seem to indicate some common phosphorescent constituent.

#### FLUORESCENCE.

Fluorescence is induced by much the same agencies as phosphorescence, but the emitted light, which may be white or colored, persists only during the action of the exciting agent. Colorless fluorite fluoresces under the influence of sunlight, autunite from Mitchell county, N. C., and hyalite from San Luis Potosi, Mexico, fluoresce wonderfully under the influence of ultra-violet light.

#### STREAK.

The streak of a mineral is the color of its fine powder. It is usually obtained by rubbing the mineral on a piece of hard, white material, such as unglazed porcelain, and brushing off the excess, or it may be obtained less perfectly by scratching the mineral with a knife or file, or by finely pulverizing a fragment of the specimen.

The streak often varies widely from the color of the mass and is nearly constant for any species. When not white it is a characteristic very useful in determination.

**TRANSLUCENCY.**

The translucency of a mineral is its capacity to transmit light. A mineral is said to be:

*Transparent.*—When objects can be seen through it with clearness.

*Subtransparent.*—When objects can be more or less indistinctly seen through it.

*Translucent.*—When light passes through, as through thin porcelain, but not enough to distinguish objects.

*Subtranslucent.*—When only the thin edges show that any light passes.

*Opaque.*—When no light appears to pass even through the thin edges.

**CLEAVAGE AND PARTING.**

Many crystallized substances when sharply struck or when pressed with a knife edge split into fragments bounded by smooth plane surfaces which are always parallel to faces of simple forms\* in which the substance can crystallize.

These surfaces are more splintery than the true crystal faces but the angles between them are just as exact as the interfacial angles.

When the separation can be obtained with equal ease in any part of the crystal and there is only a mechanical limit to the thinness of the resulting plates, the character is called *cleavage*. When, however, the separation can be obtained only at irregular intervals the character is called *parting*. Furthermore, all crystals of the same substance show the same cleavage, whereas parting may be obtained in one crystal and not in another.

When cleavage or parting is obtained parallel to one face of a crystal form it will be obtained with equal ease parallel to *all* faces of the form. For instance, galenite cleaves parallel to *all* planes of the cube, Fig. 275; calcite, Fig. 276, in three directions parallel to *all* the faces of a rhombohedron with diedral angles of  $105^{\circ} 5'$ ; and some crystals of hematite show parting planes parallel to *all* the faces of the rhombohedron.

Cleavage may be obtained parallel to the faces of two or more crystal forms, for instance gypsum splits easily into plates parallel to the clino-pinacoid, these plates again break parallel to the ortho-

pinacoid and to the dome  $\{\bar{1}01\}$  and the final shape is a rhombic plate with angles of  $66^\circ$ .

*Terms of Cleavage.* — Cleavage is said to be *perfect* or *eminent* when obtained easily, giving smooth, lustrous surfaces. Inferior

FIG. 298.



Galenite Cleavage, Pyrenees, alter Lacroix.

degrees of ease of cleavage are called *distinct*, *indistinct* or *imperfect*, *interrupted*, *in traces*, *difficult*.

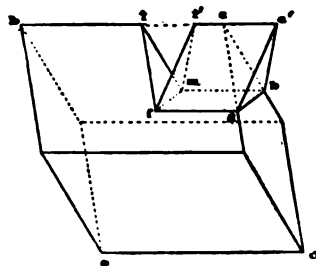
*Manipulation.* — Directions of cleavage are often indicated by a pearly lustre on faces parallel to the cleavage direction, the lustre being due to repeated light reflections from cleavage rifts, or

FIG. 299.



Calcite Cleavage.

FIG. 300.



cracks may be visible. The absence of indications is not proof that cleavage cannot be obtained, but only that previous pressure or shock have not started the separation.

Cleavage is usually obtained by placing the edge of a knife or small chisel upon the mineral parallel to the supposed direction of cleavage and striking a quick, sharp blow upon it with a hammer. In some instances the cleavage is produced by heating and suddenly plunging the mineral in cold water. Sudden heat alone will often produce decrepitation and with easily cleavable minerals the fragments will be cleavage forms.

Frequently the cleavage is made apparent during the grinding of a thin section.

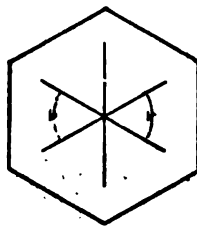
Parting is a secondary character produced in some instances and not in others as a result of pressure after solidification. It takes place along a so-called glide plane.\*

#### PERCUSSION FIGURES.

If a rod with a slightly rounded point is pressed against a firmly supported plate of mica and tapped with a light hammer, three little cracks will form, radiating † from the point, Fig. 301. The most distinct of these is always parallel to the clino-pinacoid, the others at an angle  $\alpha$  thereto which is  $53^\circ$  to  $56^\circ$  in muscovite,  $59^\circ$  in lepidolite,  $60^\circ$  in biotite,  $61^\circ$  to  $63^\circ$  for phlogopite.

In the same way on cube faces of halite a cross is developed with arms parallel to the diagonals of the face. On an octahedral face a three-rayed star is developed.

FIG. 301.



#### ELASTICITY.

Elasticity is capable of exact measurement, but is of little value in determination of minerals. The following terms are used :

*Elastic*.—A thin plate will bend and then spring back to its original position when the bending force is removed, as in mica.

*Flexible or Pliable*.—A thin plate will bend without breaking, as in foliated talc.

\* The artificial development of a glide plane  $fgbm$  in calcite is shown in Fig. 300.

If the edge  $ad$  of the larger angle is rested upon a steady support and the blade of a knife pressed steadily at some point  $i$  of the opposite edge, the portion of the crystal between  $i$  and  $c$  will be slowly pushed into a new position of equilibrium as if by rotation about  $fgbm$  until the new face  $gc'b$  and the old face  $gcb$  make equal angles with  $fgbm$ .

† By pressure alone, three cracks diagonal to these are developed.

**TENACITY.**

The following terms are used:

*Brittle*.—Breaks to powder before a knife or hammer and cannot be shaved off in slices.

*Sectile*.—Small slices can be shaved off which, however, crumble when hammered.

*Malleable*.—Slices can be shaved off which will flatten under the hammer.

*Tough*.—The resistance to tearing apart under a strain or a blow is great.

*Ductile*.—Can be drawn into wire. Every ductile mineral is malleable and both are sectile.

The sectile minerals are: graphite, bismuth, copper, silver, gold, platinum, chalcocite, agentite, molybdenite, orpiment, tetradymite, senarmontite, arsenolite, cerargyrite.

**FRACTURE.**

When the surface obtained by breaking is not a plane or a step-like aggregation of planes it is called a *fracture* and described as:

*Conchoidal*, rounded and curved like a shell, Fig. 302.

*Even*, approximately plane.

*Uneven*, rough and irregular.

*Hackly*, with jagged sharp joints and depressions as with metals.

*Splintery*, with partially separated splinters or fibers.

FIG. 302.

**HARDNESS.**

The resistance of a *smooth* plane surface to abrasion is called its hardness, and is commonly recorded\* in terms of a scale of ten common minerals selected by Mohs:

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\*In more exact testing the crystal may be moved on a little carriage under a fixed vertical cutting point and the pressure determined, which is necessary to produce a visible scratch. Other methods are planing or boring with a diamond splinter under constant pressure, and comparing the loss in weight for a given penetration or given number of movements. The loss of weight during grinding and the pressure necessary to produce a permanent indentation or a crack have also been used as determinants of hardness.

- |                                   |   |
|-----------------------------------|---|
| 1. <i>Talc</i> , laminated.       | 6. <i>Orthoclase</i> , white cleavable. |
| 2. <i>Gypsum</i> , crystallized.  | 7. <i>Quartz</i> , transparent.         |
| 3. <i>Calcite</i> , transparent.  | 8. <i>Topaz</i> , transparent.          |
| 4. <i>Fluorite</i> , crystalline. | 9. <i>Sapphire</i> , cleavable.         |
| 5. <i>Apatite</i> , transparent.  | 10. <i>Diamond</i> .                    |

Intermediate values are: *Window glass* 5.5, *Jewelers file* 6.5, *Zircon* 7.5, *Chrysoberyl* 8.5, *Carborundum* 9.5.

These numbers have no quantitative relation—there is no common difference. The diamond is much further from sapphire than this is from talc.\*

*In testing, some inconspicuous but smooth surface of the mineral is selected and a sharp point of known hardness is pressed upon the surface and moved back and forth several times on the same line a short distance ( $\frac{1}{8}$  inch). If the mineral is not scratched it is harder than the standard used, and the next higher on the scale is tried in the same way.*

A good method is to try the hardness of the mineral first with the finger nail (2.5), then with a pocket knife (about 6).

(a) If the finger nail cuts then 2 and 1 are tried.

(b) If the finger nail makes no scratch but the knife does 3, 4, 5, and 6 are tried.

(c) If the knife does not scratch the specimen the harder members, 6 to 10, are used successively until one is found which scratches the mineral.

The jewelers file and conical pencils made of the upper members of the scale are much used.

For cut stones and other valuable specimens it is often wise to use dully polished slabs of the test minerals and determine the power of an edge of the cut stone to scratch the polished test piece.

Care must be taken to distinguish between a true scratch and the production of a "chalk" mark which rubs off. Altered or rough surfaces must be avoided.

Pulverulent fibrous or splintery minerals are "broken down" or their particles pushed aside by the test and yield an "apparent" hardness often much lower than the true hardness.

---

\* The average of five attempted comparisons from 9 down give roughly sapphire 100, topaz 30, quartz 18, orthoclase 12, apatite 7, fluorite  $3\frac{1}{2}$ , calcite  $2\frac{1}{2}$ , gypsum  $\frac{1}{2}$ .

**ETCHING FIGURES**

When a crystal or cleavage is attacked by any solvent the action proceeds with different velocities in crystallographically different directions, and if stopped before the solution has proceeded far, the crystal faces are often pitted with little cavities of definite shape.

The absolute shape varies with many conditions ; time, temperature, solvent, crystallographic orientation and chemical composition.

The figures, *whatever their shape*, conform in symmetry to the class to which the crystal belongs, and are rarely forms common to several classes. They are alike on faces of the same crystal form and generally unlike on faces of different forms, and serve, therefore, as an important means (perhaps the most important) for determining the true grade of symmetry of a crystal and also for recognizing and distinguishing faces.

Fig. 303 shows the shape and direction of the etchings upon a cube of pyrite. These conform to the symmetry of the group of

FIG. 303.

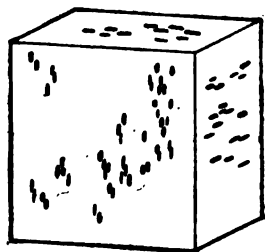
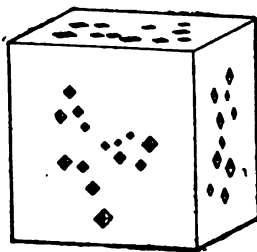


FIG. 304.



the diploid, p. 65. On the other hand the etchings upon a cube of fluorite, Fig. 304, show a higher symmetry corresponding to that of the hexoctahedral group, p. 58.

**SPECIFIC GRAVITY.**

The specific gravity of a substance is equal to its weight divided by the weight of an equal volume of distilled water. The character is an unusually constant one, the variations in varieties of the same species not being great and even these being due usually to actual differences in composition.

Strictly the temperature of the water should be 4° C., or if not the result should be multiplied by a factor which is the specific gravity of the water used. Generally the water is used at the ordinary room temperature without correction.

Pure material must be selected free from cavities, and air bubbles clinging to the surface must be brushed off while the fragment is in the water.

Substances soluble in water must be determined in alcohol, benzine or other liquids in which they are insoluble, and the result multiplied by the specific gravity of the liquid used.

The specific gravities of the minerals considered in this book range from water (ice) 0.92, to iridosmine 19 to 21.

Minerals of metallic and submetallic luster are heavy, rarely as low as 4. The great group of silicates range chiefly between 2 and 3.5, zircon reaching 4.7.

#### **Direct Weighing in a Delicate Balance.**

Except for very small material the most accurate results are obtained with a delicate balance such as an assay balance or a diamond balance, Fig. 305, within at least one tenth milligram. The

FIG. 305.



result should be correct to the third decimal. A small wooden bench, Fig. 306, is used to hold a beaker of distilled water above the scale pan, and a platinum spiral, Fig. 307, to hold the stone. Three weighings are needed :

$W$  = weight of the stone.

$S$  = weight of the spiral when suspended from the end of the



determined balance frame and immersed in the distilled water as in Fig. 307. (This weight may be made once for all.)

$W'$  = weight of the stone and the spiral suspended in distilled water.

$$\text{Then, Sp. Gr.} = \frac{W}{S + W - W'}$$

Usually no correction need be made for temperature.\*

### The Jolly Balance.

This instrument gives the *relative* weights in terms of the stretching of a spiral spring. In the older form, Fig. 308, two scale pans *c* and *d* are attached, one below the other, to a spiral spring parallel to which is a mirror with a graduated scale.

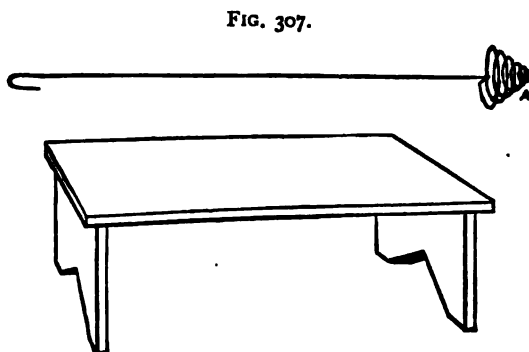
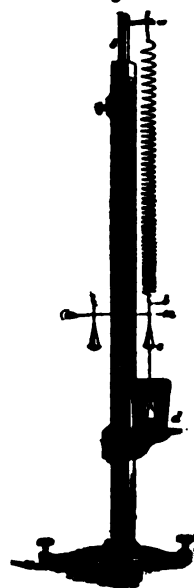


FIG. 308.



The lower pan *d* is *kept submerged* in distilled water. Three readings are made by noting the heights at which the white bead *b* on the wire and its image in the graduated mirror coincide when the spiral comes to rest.

\*Greater speed and, if proper corrections for temperature are made, equal or greater accuracy are obtained by substituting for distilled water benzol or toluol, which have less surface tension than water. The result obtained by the above formula must then be multiplied by the specific gravity of the benzol or toluol for the temperature at which the weighing was made.

- A. Instrument reading with nothing in either scale pan.
- B. Reading with mineral in upper scale pan.
- C. Reading with same fragment transferred to lower scale pan.

$$\text{Sp. Gr.} = \frac{B - A}{B - C}.$$

The result is quickly attained and unless the fragment is small is accurate to the second decimal.

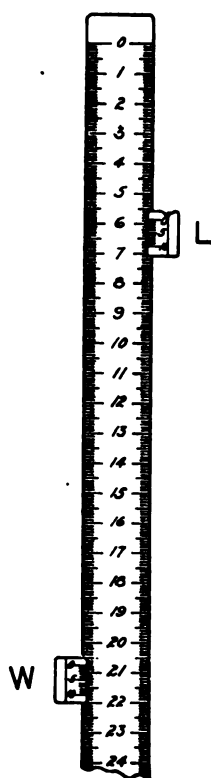
**The Kraus Recording Jolly Balance.**

Professor Kraus described \* an improved Jolly balance, Fig.

FIG. 309.



FIG. 310.



309, requiring only two readings, which may be verified at the end of the operation.

\* Described in Am. Jour. Sci., XXXI, 561, 1911. Made by Eberbach & Son Company, Ann Arbor, Mich.

The parts are : (The scale and verniers are shown enlarged, Fig. 310).

- (a) An outer rectangular tube with a fixed vernier,  $W$ .
- (b) An inner round tube movable by a milled head and carrying with it a second vernier,  $L$ .
- (c) An adjustable rod within the round tube, carrying the spring and scale pans and a pointer which swings in front of a small circular mirror.
- (d) A graduated scale which may be clamped, or if unclamped moves with the inner tube.

The operation is as follows :

1. The graduated scale, the two verniers and the pointer are all placed at zero, the lower scale pan being immersed in water.
2. The fragment is placed in the upper scale pan, the scale unclamped and the milled head turned, driving the round tube and its attachments upward until the pointer is again at zero. The reading of  $W$  corresponds to the weight in air.
3. The fragment is transferred to the lower scale pan, the scale clamped, the milled head turned till the pointer is again at zero. The reading of  $L$  corresponds to the loss of weight in water. Hence,

$$\text{Sp. Gr.} = \frac{W}{L}.$$

A minor advantage is that both weighings remain recorded until the end of the operation and may be checked.

#### Method for Small Fragments.

The difficulty of determining small grains by the chemical balance lies in the weighing in water rather than the weighing in air. The following simple method \* has been used: Substitute for the spiral a small vessel containing vaseline. Weigh this in air and water, denoting these weights by  $w$  and  $w'$ . Place several of the little crystals or grains on the vaseline and weigh in air, denoting this by  $W$ , then warm the vaseline and let them sink into it and weigh in water, denoting this by  $W'$ , then

$$\text{Sp. Gr.} = \frac{W - w}{(W + w') - (W' + w)}.$$

---

\* R. Smee, Sci. Proc. Roy. Dublin Soc., 6, 1888, 61.

**Using the Pycnometer or Specific Gravity Flask.**

Very porous minerals and powders are determined by weighing in a little glass bottle the stopper of which ends in a fine tube. In a later form there are two openings, one, the neck, is closed by a ground stopper carrying a thermometer, the other ends in a capillary tube.

In ordinary use the mineral is weighed (*A*) and the bottle full of water is also weighed (*B*). The mineral is then inserted in the bottle and displaces its bulk of water, and the difference between this weight (*C*) and the sum of the other two weights is the weight of the displaced water.

$$\text{Sp. Gr.} = \frac{A}{B + A - C}.$$

If special precautions \* are used this apparatus may be relied upon to the third decimal with one gram of substance.

Complete removal of air bubbles is secured by placing the pycnometer under an air pump after the fragments are covered with the liquid.

**Using Heavy Liquids.**

If a fragment of a mineral, which may be very minute, is dropped into a test-tube containing a liquid of higher specific gravity it will float. If the liquid is diluted, the diluent being stirred in drop by drop, there will be one stage at which the fragment if pushed down will neither sink nor rise but stay where pushed.

The specific gravity of the liquid is then determined either roughly by dropping in fragments of material of known specific gravity until one is found which just sinks and another which floats, the liquid being of a specific gravity between these; or for more accurate determination the most convenient balance is that of Westphal, Fig. 285. The beam is graduated in tenths and the weights *A*, *B* and *C* are respectively unit,  $\frac{1}{10}$  and  $\frac{1}{100}$ .

This balance is so constructed that when the thermometer float is suspended in distilled water at 15° C. a unit weight must be hung at the hook to obtain equilibrium.

If then the test-tube is nearly filled with the heavy liquid and weights added until equilibrium is secured the specific gravity is known.

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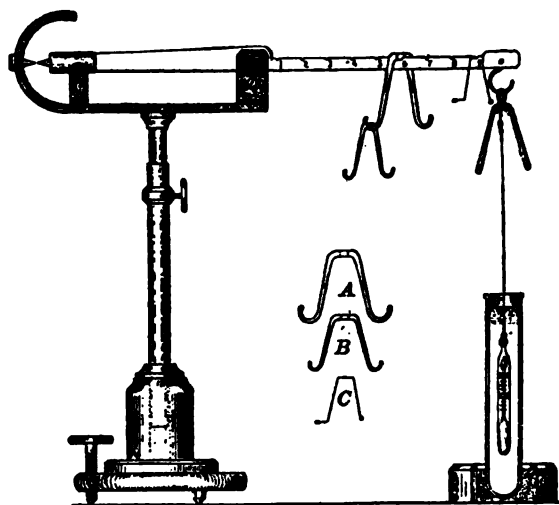
\* See Mier's *Mineralogy*, p. 191.

† For the use of heavy liquids in preparation of material for Chemical Analyses see Iddings, *Rock Minerals*, p. 25.

For instance in the figure the weights employed are :

|  |       |
|--|-------|
| Unit weight at hook, value.....                      | 1.000 |
| Unit weight at sixth division, value.....            | 0.600 |
| $\frac{1}{10}$ weight at sixth division, value.....  | 0.060 |
| $\frac{1}{100}$ weight at ninth division, value..... | 0.009 |
| Specific gravity .....                               | 1.669 |

FIG. 311.



The Westphal Balance.

The principal heavy liquids are : \*

*Thoulet Solution.*—Mercuric iodide and potassium iodide, in the ratio of five parts to four by weight, are heated with a little water until a crystalline scum forms, then filtered. The maximum specific gravity is nearly 3.1 and may be lowered by the addition of water to any desired value.

*Klein Solution.*—Cadmium borotungstate with a maximum specific gravity of 3.6 if fused, 3.3 if dissolved.

*Braun's Solution.*—Methylene iodide,  $\text{CH}_2\text{I}_2$ , with a maximum specific gravity of 3.32 which can be lowered by the addition of benzol. It darkens from exposure to light but may be clarified by shaking with a little mercury or copper.

By addition of iodoform and iodine it may be raised to a specific gravity of 3.65.

\* See *Neues Jahrb. f. Min.*, 1889, II., 185, for list of solids which when melted have specific gravity up to 5.

*Retger's Solution.*—Silver thallium nitrate which is liquid at  $75^{\circ}$  C., has a maximum specific gravity of over 4.5 which can be lowered by the addition of hot water.

#### Specific Gravity Tubes.

In gem testing, a series of tubes, usually three, fitted with glass stoppers or corks and containing liquids of different densities are sometimes used and by diluting and using "indicators," that is, fragments of a known specific gravity, the gravity of a liquid which just floats a specimen may be tested.

#### Diffusion Columns.

By pouring into a test tube a heavy liquid and on top of this a lighter liquid and allowing these to stand several hours a diffusion takes place so that the density increases regularly with the depth. By use of "indicators" the Sp. Gr. for the level to which the stone sinks may be determined.\*

#### TASTE.

Minerals soluble in water often have a decided taste :

*Astringent.* — The taste of alum.

*Saline or Salty.* — The taste of common salt.

*Bitter.* — The taste of epsom salts.

*Alkaline.* — The taste of soda.

*Acid.* — The taste of sulphuric acid.

*Cooling.* — The taste of nitre.

*Pungent.* — The taste of sal-ammoniac.

#### ODOR.

Odors are rarely obtained from minerals, except by setting free some volatile constituent. The terms most used are :

*Garlic.* — The odor of garlic obtained by heating minerals containing arsenic.

*Horseradish.* — The odor of decayed horseradish obtained from minerals containing selenium.

*Sulphurous.* — The odor obtained by heating sulphur or sulphides.

*Fetid.* — The odor obtained by dissolving sulphides in acid.

*Bituminous.* — The odor of bitumen.

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\* See Mier's Mineralogy, p. 192.

*Argillaceous*. — Obtained from serpentine and some allied minerals, after moistening with the breath.

#### FEEL.

Terms indicating the sense of touch are sometimes used :

*Smooth*. — Like celadonite or sepiolite.

*Soapy*. — Like talc.

*Harsh or Meager*. — Like aluminite.

*Cold*. — Distinguishes gems from glass.

#### THE THERMAL CHARACTERS.

##### Transmission of Heat Rays.

HEAT rays may be reflected, refracted, doubly refracted, polarized and absorbed, and it is possible, though difficult, to determine a series of thermal constants for crystals.

##### Conductivity.

The rapidity with which heat is conducted in different directions in a crystal is in accordance with its symmetry. This may be shown on any face or cleavage surface as follows :

(a) The surface is breathed upon, quickly touched by a very hot wire, dusted with lycopodium powder, turned upside down and tapped carefully. The powder falls from where the moisture film has evaporated, but adheres elsewhere, giving a sharply outlined figure. The entire operation should take less than three seconds.

(b) The surface is coated with a mixture of three parts elaidic acid and one part wax, brought into contact with a hot wire, and the temperature maintained until the wax has melted around the wire. The boundary of the melted patch is visible, after cooling, as a ridge.

A *circle* indicates either an *isometric* crystal or a basal section of a hexagonal or tetragonal crystal. All other sections yield ellipses varying in eccentricity and in position of axes.

##### Expansion.

When a crystal is uniformly heated, directions crystallographically alike expand in the same proportion, but directions unlike do not.

The expansion may be accurately measured for any direction but the methods involve apparatus of great precision and cost.

##### Change of Crystal Angles Produced by Expansion.

An *isometric* crystal uniformly heated expands without change of angles. In all other systems the expansion varies with the direction and certain angles are changed

**THE MAGNETIC CHARACTERS.**

**Magnetism.** — A few iron-bearing minerals attract the magnetic needle or are attracted by a steel magnet. Of these minerals, magnetite, pyrrhotite and platinum will themselves occasionally act as magnets.

**Para- and Diamagnetism.**

Any substances will be either attracted or repelled in some degree in the field of a strong electromagnet.

If a rod of the substance is suspended by a fiber so as to swing horizontally between the poles of an electromagnet, the rod is *paramagnetic*, if pulled into "axial" position with its ends as near the poles of the magnet as possible, and, is *diamagnetic*, if pushed into an "equatorial" position with its ends as far from the magnetic poles as possible.

Crystals are more strongly magnetized in certain directions than in others.

**Action on a Magnetic Needle. Haüy's Method of Double Magnetism.**

A delicate magnetic needle, or as Haüy showed, a needle made by a bar magnet to take an east and west position, may be attracted by stones containing iron, such as garnet, chrysolite, tourmaline.

**ELECTRICAL CHARACTERS.**

Heat, friction and pressure often develop electric charges in minerals. The charges are, however, weak and the chief differences lie in the length of time the electricity is retained.

In the testing the drier the atmosphere, the better. If humidity is great no results may be obtained. The best results are obtained from polished surfaces.

In handling the material an insulated pincers would be better than the fingers.

**Frictional Electricity.**

All minerals are electrified by friction but the + or - character may vary in varieties of a species and even in the same specimen.

The electricity is developed by brushing or striking several with a woolen cloth. Its presence is recognized by taking a stone by an insulated holder near some form of electrometer.

The duration of the charge is determined by placing the mineral stone in contact with a metal plate which is itself in contact with surrounding bodies, and in a dry room. From time to time the mineral is again tried with the electrometer.



Although Häüy devoted considerable space \* to these properties they have not been developed much since his day.

Häüy used a light brass rod with brass spheres on both ends, balanced like a magnetic needle on a fine point. This being electrified, either positively by bringing near a rod of electrified sealing wax, or negatively by touching with the rod, an electrified mineral will attract or repel the needle according as it has opposite or similar electricity.

Similarly a pith ball suspended by a silk thread may be charged and used or cat's hair may be positively electrified by rubbing between the fingers.

The *Bohnenberger-Fechner Electrometer* is a more elaborate device consisting of a single gold leaf, hanging between poles of a Zamboni dry battery. The stone is approached to the knob on the conductor. If the stone was electrified, the gold leaf becomes charged and clings to the opposite pole of the battery.

The following examples illustrate the property :

#### **Electrified Positively by Friction.**

Topaz, 24 hours duration.                      Rock crystal,  $\frac{1}{2}$  hour.

Corundum, several hours duration.          Iolite,  $\frac{1}{4}$  hour.

Odontolite, several hours duration.        Diamond,  $\frac{1}{2}$  hour.

Also spinel, tourmaline, garnet, chrysolite, beryl, spodumene, zircon, moonstone, axinite, titanite, phenacite, diopside, epidote.

Sulphur and amber are examples of minerals which develop negative electricity.

#### **Electrical Conductivity.**

All minerals conduct, but practically, conductivity is limited to the metals, some metalloids, most sulphides, tellurides, selenides, bismuthides, arsenides and antimonides, some of the oxides, and, at higher temperature, a few haloids.

If a rod is introduced into a weak current, the strength of which is varied by resistances and the deviation observed in a galvanometer, the results will vary for different minerals between very wide limits dependent upon the constitution of the chemical molecule more than upon the crystalline structure.

Practical applications of this property are the electrostatic concentrators in which the mixture falling on a moving surface is electrified more or less rapidly according to its conductivity and thereby (repelled) different distances.

Similarly a flat stick of sealing wax made electric by rubbing and held over a fine sand-like mixture will attract the better conductors ; for example, will take cassiterite from zircon.

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\* *Traité des caractères physiques des Pierres Precieuses*, Paris, 1817, pp. 113-185.

These changes may be measured with accurate goniometers and the relative expansions calculated.

#### Change of Optical Characters Produced by Expansion.

The expansion of a crystal changes the indices of refraction for different directions. With isometric crystals the index may become either larger or smaller. With tetragonal and hexagonal crystals the principal indices of refraction may alter unequally. The interference figure will also alter and for a particular temperature will disappear.

In orthorhombic, monoclinic and triclinic crystals the interference figure may undergo even more striking changes. For instance, in gypsum with yellow light at 20° C. the axial angle is 92°, at 100° C. it is reduced to 51°, at 134° C. it is zero, and for still higher temperatures the optic axes pass into a plane at right angles to their former position.

#### Melting and Inversion Points.

Fusibility in terms of a rough scale as a blowpipe test has been described, p. 164, and changes of color and other phenomena by moderate heat on p. 176.

Recent improvements in the thermoelectric couple and the electric resistance furnace have made possible laboratory determinations of the changes which minerals undergo with increased temperatures and the consequent changes in volume, etc., are of great geological importance. Both the melting point, that is "the temperature at which the crystalline and the liquid substance can remain side by side *in equilibrium*" and the inversion point, that is "the temperature at which *two* different crystalline forms of the same substance can so remain are determined."

For instance  $\alpha$  quartz changes to  $\beta$  quartz at 575° C. and to cristobalite at about 800°, and the latter melts at about 1600° C. Similarly anorthite melts at 1552°, albite below 1200°, and their isomorphous mixtures at intermediate values.

The presence of other minerals lowers the melting point and pure types, usually synthetic, are used. Natural minerals usually show a "melting interval" of 40 or 50 degrees.\*

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\* See publications of Dölter, *Neues Jahrb. f. Min.*, 11, 60, 1903. Tschermak, *Min. Mitt.*, 21, 211, 307. Also Joly, *Trans. Roy. Dublin Soc.*, 6, 283, and the more recent work of Day, White, Sosman and others, in the Geophysical Laboratory publications.

**Pyroelectricity and Piezoelectricity.**

Poorly conducting crystals which have not a center of symmetry if altered in volume either by a temperature change or by pressure will frequently accumulate positive and negative charges of electricity at different points.

**PYROELECTRICITY.** — Usually the crystal is heated in an air-bath to a uniform temperature, then drawn quickly once or twice through an alcohol flame and allowed to cool. During the cooling of the crystal positive charges collect at the so-called *antilogue* poles, and the negative charges at the *analogue* poles.

In **PIEZOELECTRICITY** the charges are developed by pressure, for instance, calcite pressed between the fingers becomes positively electrified, tourmaline compressed in the direction of the vertical axis develops a positive charge at the antilogue end and a negative charge at the analogue end or precisely the charges which would result from cooling a heated crystal.

The charges are detected by such methods as are described under frictional electricity.

*In Kundt's Method* the positive and negative poles may be distinguished by blowing upon the cooling crystal a fine well dried mixture of equal parts of powdered sulphur and red oxide of lead. The nozzle of the bellows is covered by a fine muslin net. In passing through the sieve, the sulphur is negatively electrified and is attracted by the antilogue poles, coloring them yellow, while the minimum is positively electrified and is caught by the analogue poles, coloring them red.

## CHAPTER XVI.

### CHEMICAL CHARACTERS OF MINERALS.

Minerals are either elements or are formed by the uniting of atoms of different elements in definite proportions in accordance with the laws of chemistry and for either identification or classification their chemical composition is their most important characteristic.

#### Empirical Formulas.

The chemical composition of a mineral is determined by exact quantitative analysis and from this a formula is calculated which shows which elements and how many atoms of each occur therein. Such formulas are called empirical and do not of necessity express the structure of the molecule,\* but only the composition ratio. In fact, the symbols adopted are always the simplest which can express the proportions shown by analysis to exist between the atoms and which satisfy their valences.

#### Calculation of Formulas.

A very pure specimen of beryl gave the following results on analysis:

|  | Per cent. |
|--|-----------|
| BeO, . . . . .                           | 14.01     |
| Al <sub>2</sub> O <sub>3</sub> . . . . . | 19.26     |
| SiO <sub>2</sub> , . . . . .             | 66.37     |

The sum of the atomic weights for each group is:

$$\text{BeO} = 25.$$

$$\text{Al}_2\text{O}_3 = 102.$$

$$\text{SiO}_2 = 60.$$

The results of analysis represent the proportion in which the groups are present in the molecule. Consequently, the relation between the number of groups must be:

\* True molecular formulas can not be given to minerals, for they are volatile or soluble only in rare instances, and are probably always some unknown multiple of the empirical.

| Percentage Composition. |   | Atomic Weights. |   | Proportionate Number of Groups. |
|-------------------------|---|-----------------|---|---------------------------------|
| 14.01                   | ÷ | 25              | = | .56                             |
| 19.26                   | ÷ | 102             | = | .189                            |
| 66.37                   | ÷ | 60              | = | 1.106                           |

Now, as fractional atoms cannot exist, our problem is simply to find the smallest number of whole groups which stand to each other in this relation, and, as  $.56 : .189 : 1.106 = 3 : 1 : 6$ , very nearly, therefore, the composition is represented by  $3\text{BeO} + \text{Al}_2\text{O}_3 + 6\text{SiO}_2$ , which may be better written  $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ , or, as it at once becomes evident that the proportion between silicon and oxygen is that of a metasilicate,  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ .

It will now be found, on calculating the theoretical percentage composition of  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ , that it agrees within the limits of error with that found by analysis, and as the twelve affinities of the six  $\text{SiO}_3$  radicals are satisfied by those of Be and Al atoms, the formula probably represents the composition of the compound. The true molecular formula is, however,  $n\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$  wherein  $n$  represents some whole number. In this way the formulas of many minerals have been settled beyond question, while for others this success has not been reached.

#### ISOMORPHISM.\*

Frequently the results of analyses show that the minerals contain elements foreign to their true composition. These may be present as impurities but if the mineral is homogeneous it is usually found that these unexpected elements replace analogous elements of the true molecule. Many beryls, for instance, contain Cs, H<sub>2</sub>, Na<sub>2</sub>, Ca, or Mg replacing Be; and Fe or Cr replacing Al. This replacement is explained by the principle of isomorphism.

#### Isomorphous Substances.

Substances are said to be isomorphous if they fulfill the following conditions:

(a) Show distinct similarity in their molecules and a close resemblance in their reactions,

\* Absolute isomorphism does not exist except in the isometric substances. The replacement of one element for another in either all or part of the molecules produces some change in the angles.

(b) Crystallize in forms which in the regular system are identical, and in the other systems are so closely related as to require, at times, special care in angle measurement to recognize any difference.

(c) *Are capable of mixing in varying proportions to form homogeneous crystals.*

The third condition is the most important.\* The others have no recognized limit.

For instance the orthorhombic sulphates form an isomorphous series.

| Species.       | Type Formula.     | Axial Ratio.<br>$a:b:c$ . | Prism Angle,<br>$110:110$ . | Dome Angle,<br>$102:102$ . |
|----------------|-------------------|---------------------------|-----------------------------|----------------------------|
| Barite.....    | BaSO <sub>4</sub> | .815 : 1 : 1.313          | 78° 22'                     | 77° 43'                    |
| Celestite..... | SrSO <sub>4</sub> | .779 : 1 : 1.280          | 75° 50'                     | 78° 49'                    |
| Anglesite..... | PbSO <sub>4</sub> | .785 : 1 : 1.289          | 76° 16'                     | 78° 47'                    |
| Anhydrite..... | CuSO <sub>4</sub> | .893 : 1 : 1.008          | 83° 33'                     |                            |

These not only occur as the type minerals but as mixed crystals known as calcio-celestite, barylocelestite, leedsite, etc.

The carbonates form *two* characteristic isomorphous groups, the first orthorhombic and the second rhombohedral.

|                                       | Axial Ratio,<br>$a:b:c$ . | Prism Angle,<br>$119 \wedge 110$ . |
|---------------------------------------|---------------------------|------------------------------------|
| Aragonite, CaCO <sub>3</sub> .....    | .622 : 1 : .720           | 63° 48'                            |
| Strontianite, SrCO <sub>3</sub> ..... | .609 : 1 : .724           | .62° 41'                           |
| Witherite, BaCO <sub>3</sub> .....    | .603 : 1 : .730           | 62° 12'                            |
| Cerussite, PbCO <sub>3</sub> .....    | .610 : 1 : .723           | 62° 46'                            |

Bromlite, (Ba.Ca)CO<sub>3</sub>, Emmonite, (Sr.Ca)CO<sub>3</sub>, are instances of mixed crystals with extensive replacement. Many occurrences show smaller replacement.

|  | Axial Ratio $\frac{c}{a}$ . | Rhombohedral. |
|--|-----------------------------|---------------|
| Calcite, CaCO <sub>3</sub> .....       | .854                        | 74° 55'       |
| Siderite, FeCO <sub>3</sub> .....      | .818                        | 73° 0         |
| Smithsonite, ZnCO <sub>3</sub> .....   | .806                        | 72° 20'       |
| Magnesite, MgCO <sub>3</sub> .....     | .811                        | 72° 36'       |
| Rhodochrosite, MnCO <sub>3</sub> ..... | .818                        | 73° 0         |

In this group the mixed crystals are exceedingly common and many variety names exist usually involving the name of the principal replacing element such as manganocalcite, ferriferous rhodochrosite, calciferous siderite, etc. In addition there are double salts such as dolomite, CaMg(CO<sub>3</sub>)<sub>2</sub>, and subspecies ankerite, (CaCO<sub>3</sub>)<sub>2</sub>(Mg.Fe.Mn)CO<sub>3</sub>.

\* Retger's rule is: "Two substances are truly isomorphous if the physical properties of their mixed crystals are continued functions of their chemical composition."

### Isomorphous Mixtures or Homogeneous Mixed Crystals.

When two or more isomorphous substances mix to form homogeneous crystals the resulting solids are variously called "homogeneous mixed crystals," "isomorphous mixtures" and "solid solutions."\*

Most mineral species are isomorphous mixtures and their color, specific gravity, fusibility and other qualities may vary widely in consequence.

Although it is generally held that mixed crystals consist of isomorphic molecules united "like stones in a building" it is convenient to regard them as formed by the replacement of one element or radical by another isomorphous with it, rather than as a mixture of different individual molecules.

The principle of isomorphic replacement is well illustrated in the garnets which have the class formula  $R_2''R_3'''(SiO_4)_3$  in which  $R''$  stands for any combination of the isomorphous divalent atoms Ca, Mg, Fe'', Mn taken three at a time and  $R'''$  denotes any combination of the isomorphous trivalent atoms Al, Cr or Fe'''.  
Therefore while the typical species

|                                   |                                  |
|-----------------------------------|----------------------------------|
| Grossularite, $Ca_3Al_2(SiO_4)_3$ | Spessartite, $Mn_3Al_2(SiO_4)_3$ |
| Pyrope, $Mg_3Al_2(SiO_4)_3$       | Andradite, $Ca_3Fe_3(SiO_4)_3$   |
| Almandite, $Fe_3Al_2(SiO_4)_3$    | Uvarovite, $Ca_3Cr_3(SiO_4)_3$   |

have the formulas assigned to them; when pure they are in fact seldom found on analysis to more than approach these formulas. For instance:

|                      | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | CaO   | MnO   | FeO   | MgO  | Fe <sub>2</sub> O <sub>3</sub> |
|----------------------|------------------|--------------------------------|-------|-------|-------|------|--------------------------------|
| <i>Grossularite:</i> |                  |                                |       |       |       |      |                                |
| Theoretical.....     | 40               | 22.7                           | 37.3  | —     | —     | —    | —                              |
| Vesuvius.....        | 39.8             | 20.16                          | 35.42 | 0.46  | 1.21  | 0.97 | 1.03                           |
| Jordansmühl.....     | 37.8             | 21.13                          | 31.28 | 0.45  | 4.19  | 2.88 | —                              |
| <i>Spessartite:</i>  |                  |                                |       |       |       |      |                                |
| Theoretical.....     | 36.4             | 20.60                          | —     | 43.0  | —     | —    | —                              |
| Glen Skiag.....      | 35.99            | 16.22                          | 0.40  | 15.24 | 23.27 | 0.47 | 8.64                           |

Accordingly garnets vary through all combinations of color, with wide divergence of composition. Still their crystalline forms are identical and their composition can be expressed as of a definite type.

### Formulas of Isomorphous Mixtures.

The formulas are calculated from the analyses as before by dividing the percentage composition by the molecular weight of the radical (or atomic weight of the element).

\* The term solid solution includes also non-isomorphous combinations. Any solution of a solid in a solid.

For instance, the spessartite from Glen Skiag.

| Percentage.                          |       |   | Molecular Weight. | Ratio.  |       | Number of Groups. |
|--------------------------------------|-------|---|-------------------|---------|-------|-------------------|
| MnO.....                             | 15.24 | + | 71                | = .2146 | .5568 | 3                 |
| FeO.....                             | 23.27 | + | 71.9              | = .3236 |       |                   |
| MgO.....                             | 0.47  | + | 40.36             | = .0116 |       |                   |
| CaO.....                             | 0.40  | + | 56.10             | = .0070 |       |                   |
| Al <sub>2</sub> O <sub>3</sub> ..... | 16.22 | + | 102.2             | = .1587 | .2128 | 1.14              |
| Fe <sub>2</sub> O <sub>3</sub> ..... | 8.64  | + | 159.8             | = .0541 |       |                   |
| SiO <sub>2</sub> .....               | 35.99 | + | 60                | = .5998 | .5998 | 3.23              |

This only approximates a garnet formula, giving



and probably indicates some loss of divalent elements by weathering, or some inter-mixed impurities.

A black sphalerite from Felsobanya, Hungary, gave:

| Percentage. |       | Atomic Weight. |      | Ratio. |       | Number of Groups. |   |
|-------------|-------|----------------|------|--------|-------|-------------------|---|
| S.....      | 33.25 | +              | 32   | =      | 1.039 | 1.040             | I |
| Zn.....     | 50.02 | +              | 65.4 | =      | .756  |                   |   |
| Fe.....     | 15.44 | +              | 56   | =      | .276  |                   |   |
| Cd.....     | .30   | +              | 112  | =      | .003  |                   |   |
| Pb.....     | 1.01  | +              | 207  | =      | .005  |                   |   |

In expressing the composition of an isomorphous mixture by formulas the letter R is used to represent a varying group of isomorphous or equivalent elements, and it may have the valency of these elements designated by dots above and to the right of the letter. When elements are placed in a parenthesis with a period between, as (Zn.Fe)S, it means, that the zinc and iron *taken together* are equivalent to one atom of sulphur.

#### GEL MINERALS AND ADSORPTION.

There are a series of mineral products, all results of weathering or hot springs action, which by their lack of uniform composition, generally amorphous structure and external appearance suggest that they are "hydrogels," that is, products of the colloidal condition. In common with artificial "hydrogels" they take up or "adsorb" foreign material from solution in proportions independent of molecular weights and independent of crystalline similarity. Although such "hydrogels" are homogeneous and not mechanical mixtures, they are like solutions rather than definite chemical compounds and no way is known by which to



tell which constituents are united and which adsorbed. No constancy in analysis is to be expected and no good formulas will result.

#### CHEMICAL ALTERATIONS.

The results of alteration through atmospheric agencies, infiltration of water, etc., tend at times to so alter the individual that its composition varies widely from the type. New species may form and frequently the original mineral and its alteration product may both be present in the same fragment or crystal.

In general the new material is softer and less coherent than the original and the microscope quickly proves the lack of homogeneity.

#### CHEMICAL TYPES.

Minerals like other definite chemical compounds are either elements, oxides, acids,\* bases or salts, the last being by far the most numerous.

1. *The Elements*, as Au, Ag, Cu, Sb, C, S. These are frequently alloyed with other elements as copper with silver, sulphur with selenium, etc. Only about one fifth of the known elements occur "native," that is as minerals.

2. *Oxides*. Elements in combination with oxygen, such as cuprite,  $\text{Cu}_2\text{O}$ , cassiterite,  $\text{SnO}_2$ , hematite,  $\text{Fe}_2\text{O}_3$ . Only about a dozen are sufficiently common to be described in this book.

3. *Hydroxides*. (Bases.) Containing hydroxyl (OH) as an important radical, as brucite,  $\text{Mg}(\text{OH})_2$ , limonite,  $\text{Fe}_2\text{O}_3(\text{OH})_3$ . Very few of these are described.

4. *Acids*. The only example described is sassolite,  $\text{H}_3\text{BO}_3$ .

5. *Salts*. Most minerals can be considered as derived from known or hypothetical inorganic acids, and in many instances they have been artificially produced in the laboratory as normal, acid or basic† salts of these acids.

\* As defined under the ionic theory:

Acids are compounds, the dilute water solutions of which contain hydrogen ions.

Bases or hydroxides are compounds, the dilute water solutions of which contain hydroxyl (OH) ions.

Salts are formed by union of base with acid, water also forming.

† In normal salts all of the hydrogen of the acid or hydroxyl of the base have been replaced by metallic elements or acid radicals respectively. In acid salts only part of the hydrogen has been replaced. In basic salts only part of the hydroxyl has been replaced.

The most important groups of salts are:

The Sulphides, derivatives of  $H_2S$  and to a less extent their analogues the selenides, tellurides, arsenides and antimonides, as galenite,  $PbS$ , clausthalite,  $PbSe$ , hessite,  $Ag_2Te$ , niccolite,  $NiAs$ .

The Chlorides, derivatives of  $HCl$ , and to a less extent their analogues the fluorides, bromides and iodides as halite,  $NaCl$ , fluorite,  $CaF_2$ , bromyrite,  $AgBr$ , iodyrite,  $AgI$ .

The Carbonates, derivatives of  $H_2CO_3$ , as calcite,  $CaCO_3$ ; basic salts of carbonic acid also occur, as malachite,  $Cu_2(OH)_2CO_3$ .

The Sulphates, derivatives of  $H_2SO_4$ , as barite,  $BaSO_4$ .

The Phosphates, derivatives of  $H_3PO_4$ , as vivianite,  $Fe_3(PO_4)_2 + 8H_2O$ .

The Silicates. By far the largest subdivision. They may generally be considered as derivatives of orthosilicic acid,  $H_4SiO_4$ , as chrysolite  $(Mg.Fe)_2SiO_4$ , metasilicic acid,  $H_2SiO_3$ , as rhodonite,  $MnSiO_3$ , or some hypothetical polysilicic acid, as  $H_4Si_3O_8$ , represented by orthoclase,  $KAlSi_3O_8$ .

Less common are: nitrates, derivatives of  $HNO_3$ , chromates, derivatives of  $H_2CrO_4$ , and of  $HCrO_3$ , molybdates, derivatives of  $H_2MoO_4$ ; tungstates, derivatives of  $H_2WO_4$ ; borates, derivatives of  $HBO_3$ ,  $H_3BO_3$  or of  $H_2B_4O_7$ ; aluminates, derivatives of  $HAIO_3$ ; arsenates, derivatives of  $H_3AsO_4$ ; vanadates, derivatives of  $H_3VO_4$ ; columbates, derivatives of  $HCrO_3$ ; sulpharsenites, derivatives of  $H_3AsS_3$  and their analogues the sulphantimonides.

### Water of Crystallization.

The water given off when hydroxides or acid or basic salts are heated is usually expelled only under a temperature approaching a red heat. Such water is not reassumed in the presence of moisture, and is not considered to be present in the mineral as water but to be in intimate combination. Its loss destroys the original mineral.

In other minerals water is given off at relatively low temperatures, sometimes at common temperatures (laumontite), sometimes by a slight increase (gypsum) or below  $300^\circ$ , natrolite. Such water is frequently reassumed by the mineral in the presence of moisture and the physical properties may remain unaltered. That is the release of the water has not destroyed the original substance, and it is assumed to be present in the minerals as water (called *water of crystallization*) and is expressed in the formula as molecules of  $H_2O$ , thus gypsum,  $CaSO_4 + 2H_2O$ .

**MICROCHEMICAL METHODS.**

"The application of chemical operations to the examination and study of very small quantities of material."

The tests are either tests for elements or tests which by color changes, etchings, etc., of polished surfaces give clues to species. Both require much practice and are as yet largely reserved for special investigation and little used in general mineralogical testing. The recent works of Chamot\* and Murdoch† should be consulted.

In the study of the rock-forming silicates, especially in their more minutely crystallized varieties, tests for certain great elements such as Al, Ca, Mg, K, Na are desirable and the crystallized fluo-silicates obtained by the Boricky method by treatment of the silicates with hydrofluoric acid as well as the series of crystals obtained by the Behren's method by treatment with hydrofluoric and sulphuric acids and subsequent addition of different reagents to the resulting sulphate solutions are used to some extent. Both are described in Luquer's "Minerals in Rock Sections," pp. 136-139.

A few microchemical tests and re-crystallizations are described in parts of the book. It has not seemed necessary to tabulate them.

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\* "Elementary Chemical Microscopy," John Wiley & Sons, 1915.

† "Microscopical Determination of Opaque Minerals," John Wiley & Sons, 1916.

## CHAPTER XVII.

### THE FORMATION AND OCCURRENCE OF MINERALS.

The solid crust of the earth consists almost entirely of minerals, of which about a thousand species have been identified, which involve in their composition practically all of the known elements.

But the vast mass of the crust consists of aggregations\* of a few great silicates composed almost entirely of nine elements themselves calculated† to constitute over 98 per cent. of the crust in the following proportions:

|         |       |         |      |         |      |
|---------|-------|---------|------|---------|------|
| O.....  | 49.85 | Fe..... | 4.12 | Na..... | 2.33 |
| Si..... | 26.03 | Ca..... | 3.18 | K.....  | 2.33 |
| Al..... | 7.28  | Mg..... | 2.11 | H.....  | 0.97 |

The remaining species involving the eighty elements are in part disseminated in these aggregations or rocks‡ in minute amounts but are largely concentrated in special deposits, pegmatite veins, ore veins, contacts, saline residues, etc.

The history of a mineral, the rôle it has played, is largely told by the occurrence and associates and alternations but these must be considered according to certain fundamental principles of mineral formation which have been revealed by consideration of formations still going on and laboratory experiments.

#### Associates (Paragenesis).

This association may be accidental, as in a conglomerate, but the association in the rock in which they were formed may reveal much as to the order of formation, the processes which were active, and the temperature and pressure during formation.

#### Alteration and Pseudomorphs.

The alterations show whether the changes are essentially structural, involving a molecular rebuilding or essentially chemical

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\* F. W. Clarke, U. S. Geol. Survey, Bull. 491, p. 33.

† Of the remaining 1.8 per cent. ten other elements in order, Ti, Cl, C, P, S, Fl, Ba, Mn, Sr, N, are estimated to total 1.33 per cent. leaving 0.47 for the remaining sixty-odd elements.

‡ Aggregations of minerals large enough to be of geological significance and constant enough in characters to be identified are called rocks.

with oxidation, reduction, partial solution, or the entire removal of one substance and its replacement by another.

Frequently minerals are found as "pseudomorphs," that is, in crystalloids, the shapes of which belong to some other mineral. In many instances these are merely casts or incrustations which involve little as to the process, but in other instances they are evidently the result of the gradual and often incomplete alteration of the original mineral and give important clues to the process of alteration and add weight to synthetic experiments by showing that in nature similar changes actually occur.

Petrifications differ from pseudomorphs principally in that they are alterations or replacement of organic remains by mineral substances.

### Physical and Chemical Characters.

Any conclusion as to the origin or mode of formation of a mineral must be in conformity with its observed physical and chemical characters. For instance, the solubility is a most important factor in determining the order of separation whether from aqueous or fusion solutions. Leucite crystals are isometric in shape, but their optical characters indicate a system of lower symmetry unless the material is heated to  $433^{\circ}\text{C.}$ , the conclusion is that these isometric crystals formed above  $433^{\circ}$ . Cyanite at about the melting point of copper assumes the characters of sillimanite, hence, ignoring the effect of pressure, it formed below that temperature.

### Synthetic Production of Species and of Alterations.

The successful reproduction of a mineral by a method which does not conflict with the known natural conditions is an important clue as to its probable origin,\* but is not conclusive, for the same species is often made in several ways. For instance: orthoclase has been formed from fused magma, from sublimation and in the wet way and by action of solutions on leucite, and galenite has

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\* The production of species synthetically has several other purposes, such as settling its composition:

1) By producing crystals identical in characters with those of some natural substance but avoiding the frequent natural inclusions, weathering, etc., which lead to wrong analyses.

2) Obtaining crystals of massive or poorly crystallized minerals.

3) Obtaining simple types which are rare in nature and finding new members of groups.

been formed by sublimation, by electrochemical reactions and by superheated water in a sealed tube.

On the other hand, probable theories which have not been synthetically checked are not necessarily wrong. The processes of nature are not all to be reproduced, especially the geologic periods of time.

So also the alteration of a mineral in the laboratory or even the production of pseudomorphs by possible natural methods may be of value as indicating what would happen under similar conditions maintained longer periods.

The method of synthesis chosen must conform as far as possible with the observed conditions, must employ reagents that occur in nature and are thought to have taken part in the making. Geologic time may be in part compensated for by increased pressure and a temperature of  $100^{\circ}$  to  $300^{\circ}$ ; microscopic crystalline crusts must often be accepted as the equivalent of larger natural crystals.

#### THE PROCESSES OF MINERAL FORMATION.

The processes of mineral formation may be broadly grouped under the headings:

1. Crystallization from molten silicate magmas.
2. Formation by pneumatolysis, that is, processes in which gases and vapors play a prominent part.
3. Crystallization or precipitation from aqueous solutions.

#### CRYSTALLIZATION FROM MOLTEN SILICATE MAGMAS.

Below the present crust of the earth the regularly increasing temperature and pressure indicate that at some depth everything must be a fluid mass. This fluid mass or magma by volcanic forces penetrates any crack or crevice in the crust above, sometimes reaching and overflowing at the surface (volcanic rocks) at other times being forced between strata far below the surface (plutonic rocks).

#### The Nature of a Magma.

The fluid magma consists chiefly of silicates but partly of oxides, sulphides, fluorides and ferrates mutually dissolved in each other with certain volatile constituents, chiefly water.

As it cools the various minerals separate partly as type species, partly as mixed crystals.

The order of separation rests more on solubility than fusibility\* and much upon eutectic ratios, for in a cooling mass if more than the proportion of one constituent is present than is necessary to form the "eutecticum" or mixture with lowest melting point *that* constituent would separate first.†

Other factors such as supersaturation exist, the number of components is considerable, the composition of the magma is constantly changing and the problem is very complex.

#### FORMATION BY PNEUMATOLYSIS.

Pneumatolysis is Bunsen's name for those processes in which gases and vapors play an important part. Aqueous solutions may contribute to the reaction.‡

Usually, the term is limited to the action of gases and vapors on preëxisting minerals, but is here allowed to include certain minor processes.

#### The Gases and Vapors.

Volcanoes emit much steam§ and relatively small amounts of other vapors, often at first O and N, mixed about as in air, and a little H, and later, probably by the action of the steam and the high temperature in decomposing existing compounds, there arise vapors of HCl, SO<sub>2</sub>, SO<sub>3</sub>, H<sub>2</sub>S, CO<sub>2</sub>, CO, Cl, CH<sub>4</sub>, HF, SiF<sub>4</sub>, B<sub>2</sub>O<sub>3</sub>.

Similar gases and vapors are released from slowly cooling magma which force themselves into the already solidified magma and the neighboring rocks and produce new minerals and recrystallizations.

The gases and vapors act as solvents and also as "mineralizers" much as in the many experiments with sealed tubes and frequently the action is catalytic as in many such experiments.

Pneumatolytic action has occurred:

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\* Quartz fusible at 1625° often begins to crystallize at 1100 to 1200°. Vesuvius lavas are still molten at 1100°. The nearly infusible leucite, for instance, in a leucite-tephrite magma goes into a solution at a little above red heat and separates at a red heat.

† For instance, the eutecticum of chrysolite Mg<sub>2</sub>SiO<sub>4</sub> and diopside CaMgSi<sub>2</sub>O<sub>6</sub> is 32 per cent. chrysolite, 68 per cent. diopside. In a cooling mass if more than 32 per cent. chrysolite were present chrysolite would separate first, with less chrysolite diopside would separate first.

‡ Above the critical temperature, which for water is 375° C., physical differences between the gaseous and liquid conditions cease.

§ One minor cone of Etna is estimated to have discharged vapor at rate of 4,620,000 gallons per day.

- (a) Around volcanoes by action of vapors and gases on country rock and on minerals already formed from exhalations.
- (b) In pegmatite veins.
- (c) In contacts.
- (d) In and near tin lodes.
- (e) In some apatite veins.
- (f) In silver and gold veins near younger\* eruptives.

#### Minor Processes Involving Gases and Vapors.

In certain instances the formation does not involve preëxisting solids but is either

- (a) Due to the mixing of two gases or vapors.
- (b) Due to the decomposition of gases or vapors by heat.

In other instances "sublimates" form at cooling which may be true sublimates, involving no change of chemical composition or may be of more complicated origin.

#### CRYSTALLIZATION OR PRECIPITATION FROM WATERY SOLUTIONS.

Water is the chief agent in the alteration and concentration of minerals.

Distilled water at ordinary temperatures and pressures will dissolve large amounts of the soluble salts and small amounts of almost all other substances, for instance, in per cents. gypsum 0.25, calcite 0.0025, barite 0.0002; anhydrous silicates very slightly and quartz so slightly that no numbers have yet been found to express it. Increased temperature and pressure in general increase solubility.

#### Rain Water.

Rain water is the principal cause of the decay or weathering of rocks. In passing through the atmosphere it absorbs about 0.65 per cent. oxygen and 0.03 per cent. carbon dioxide. This charged water possesses greatly increased solvent power and an oxidizing action.

For instance, water saturated with  $\text{CO}_2$  dissolved 0.10 to 0.12 per cent. of calcite or forty times as much as pure water.

More important, however, as bearing upon the alteration of silicates, is that water containing carbonic acid or alkaline carbonates in solution will decompose many silicates.

Free oxygen may oxidize sulphides and arsenides and further oxidize oxides or even drive out  $\text{CO}_2$ , for instance forming hematite from siderite,  $4\text{FeCO}_3 + 2\text{O} + 3\text{H}_2\text{O} = 2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O} + 4\text{CO}_2$ .

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\* Called propylization and consisting in the change of the original minerals of the eruptive to chlorite, clay, calcite, pyrite, etc.



Rain water also mechanically sorts and transports the less soluble portions and by streams carries the soluble portions to marshes, lakes and seas, where ultimately by evaporation new mineral deposits develop.

The minerals are not attacked with the same rapidity, the presence of certain elements seeming to be the principal determining factor:

*Calcium* bearing minerals are most readily attacked and the  $\text{CaO}$  is largely carried away.

*The alkalis*, soda and potash, also form soluble salts but the  $\text{Na}_2\text{O}$  is principally carried off in solution, while the  $\text{K}_2\text{O}$ , to a great extent, recombines to new species.

*Magnesium* is slightly carried off but for the most part forms hydrous magnesia minerals.

*Ferric oxide* is not much attacked. *Ferrous oxide* largely combines with oxygen and water to form limonite.

Most of the *alumina* and *silica* remain but with some formation of colloidal aluminous silicates and silicic acid.

The leached products possess a certain power to reabsorb lost substances, clays and soils take up potash, hydroxides of iron also absorb.

#### Underground Water.

The rain water in part sinks through the soil, penetrating by pores and fissures to considerable depths,\* and with infiltrations from lakes, ocean and water courses and smaller amounts of water from ancient sediments or released by cooling magmas,† forms the so-called "underground or ground water."

In the upper portions there is free circulation, the action is essentially that of rain water, solution and oxidation and much of the water returns to the surface by springs.

Lower there is less circulation, the water is poorer in oxygen than rain water, but contains in solution such salts as carbonates of calcium, magnesium, potassium and sodium, or locally chlorides and sulphates.

The action is more varied than at or near the surface.

Organic materials may cause reduction to lower oxides or native metals, and of alkaline sulphates to sulphides, which then are able to precipitate sulphides from silicates, carbonates and sulphates of the metals. Under the increased pressure the water tends to enter into combination.

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\* Said in extreme cases to be 10,000 feet.

† Cooling igneous rocks and late phases of an intrusion may release water often carrying in solution metallic ores, sulphur, boron, fluorine, etc.

**THE SEPARATION OF SOLID COMPOUNDS FROM WATERY SOLUTIONS.**

The principal methods by which the constituents of a watery solution are separated from the solution as solids are:

**I. Decreased Solvent Power by :**

(a) *Decreased pressure or temperature*, as in the case of solutions rising from below.

(b) *Evaporation*. — This is practically restricted to the seas and lakes at the surface, as in the interior the hollows are soon filled with water vapor.

(c) *Loss of a Constituent*. — A loss of  $\text{CO}_2$  takes place in moving water in contact with air, as at outlets of springs or rivers.

(d) *Solution of Another Substance*. — Solutions saturated with one substance can dissolve another, but a saturated complex solution contains less of either salt than when saturated by it alone. Hence a saturated solution coming in contact with a new substance may dissolve some of it, but if so will deposit some of the substance previously in solution.

**II. Precipitation.**

The precipitation of a mineral may take place as follows:

(a) As the result of the meeting of two solutions.

(b) By the action of gases upon a solution.

(c) By electrolytic action, probably.

(d) By the action of a solid upon a solution.

Very dilute solutions and slow action are favorable to well-developed crystalline material.

The law of mass action rules, that is, each material exerts chemical action proportionate to its mass. Exactly opposite results are obtainable; for instance,  $\text{BaCO}_3$  with sufficient sulphate solution is all changed to  $\text{BaSO}_4$  and  $\text{BaSO}_4$  with sufficient carbonate solution is all changed to  $\text{BaCO}_3$ . If the quantity of solution is not sufficient, a stage is reached in which both salts are simultaneously in solution.

**III. Metasomatic Replacement.**

Replacement, or metasomatic replacement, while often involving a complicated series of chemical reactions, implies always the action of a solution on an existing mineral in such a way that as each particle of the mineral is dissolved it is *immediately* replaced by a particle of another mineral of different chemical composition.

**MINERAL OCCURRENCES.**

The occurrence of minerals may be discussed under the following headings:

- A. The Great Mineral Aggregates or Rocks.
- B. The Minerals Produced During the Cooling of a Magma.
  - 1. The Minerals which Crystallize from Molten Silicate Magmas.
  - 2. Pegmatite Veins and their Minerals.
  - 3. Magmatic Segregations and their Minerals.
  - 4. Zeolites.
  - 5. The Minerals Formed near Volcanoes.
- C. The Minerals Produced by Weathering and the Weathering Solutions.
  - 6. The Minerals of the Mechanical Sediments.
  - 7. The Minerals of the Chemical Sediments.
  - 8. The Minerals of the Sediments due to Organisms.
- D. Metamorphic Minerals and Vein Minerals.
  - 9. The Minerals of Contacts.
  - 10. The Minerals of Regional Metamorphism.
  - 11. The Minerals of Veins and Replacements.

#### A. THE GREAT MINERAL AGGREGATES OR ROCKS.

Practically all minerals are constituents of igneous, sedimentary, or metamorphic rocks.

#### Igneous or Eruptive Rocks.

About ninety-five per cent. of the crust of the earth consists of rocks which come from the interior of the earth as molten silicate magmas. See page 241. These molten magmas were forced up into crevices in the crust above, sometimes reaching and overflowing at the surface (volcanic rocks\*), at other times formed deep within the earth (plutonic rocks†).

Evidently the same magma may form both plutonic and volcanic rocks containing essentially the same mineral species.

The great plutonic and volcanic rocks and their dominant minerals are:

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\* The volcanic rocks having cooled rapidly are often glassy, or fine-grained with constituent minerals unrecognizable to the eye alone or with flow structures and steam cavities. Below the surface they show less glass and more and larger crystals often with glassy inclusions.

† The plutonic rocks having cooled slowly at great depths are solid and coarsely crystalline with recognizable constituent minerals and do not often contain glassy inclusions. Liquid inclusions are frequent.

| Plutonic.       | Volcanic.     | Dominant Minerals.                       |
|-----------------|---------------|--|
| Granite.....    | Rhyolite..... | Quartz and orthoclase.                   |
| Syenite.....    | Trachyte..... | Orthoclase with mica or hornblende.      |
| Diorite.....    | Andesite..... | Plagioclase with hornblende or biotite.  |
| Gabbro.....     | Basalt.....   | Plagioclase with pyroxene or chrysolite. |
| Peridotite..... |               | Chrysolite pyroxene, hornblende.         |

### The Sedimentary Rocks.

The volcanic rocks and the plutonic rocks which by erosion or upheaval reach the surface undergo a process of breaking down partly chemical, partly mechanical, by the combined action of rainwater with its contained oxygen and carbonic acid, unequal expansion due to varying temperatures, the action of glaciers, living and decaying organic matter and other factors.

The residual solid material and the weathering solutions form new so-called sedimentary rocks, which in general are stratified and less firm and coherent than igneous rocks.

### The Mechanical Sediments.

The residual solid material is to some degree mechanically sorted by water, wind or glaciers into the coarser grains containing more unaltered material and finer grains containing more colloidal and hydrated material. By pressure and the cementing action of materials deposited from percolating waters these deposits of gravel, sand and clay are reconsolidated into conglomerates, sandstones and shales,\* the shales being by far the most abundant.

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\* Average compositions are:

|                      | Sandstones (Clarke). | Shales (Leith and Meade). |
|----------------------|----------------------|---------------------------|
| Quartz.....          | 66.8                 | 31.91                     |
| Feldspars.....       | 11.5                 | 17.60                     |
| Clay.....            | 6.6                  | 10.00                     |
| Iron hydroxides..... | 1.8                  | 4.75                      |
| Carbonates.....      | 11.1                 | 7.90                      |
| Sericite.....        |                      | 18.40                     |
| Other minerals.....  | 2.2                  | 9.44                      |

The sandstones and conglomerates consist for the most part of visible fragments of the minerals of the igneous rocks, cemented by calcium carbonate, silica, clay, ferric hydroxide, calcium and barium sulphates.

The shales form from finer particles with much colloidal material (silicic acid, clay, etc.) and adsorbed alkalis and alkaline earths. In drying the colloidal material almost disappears, fine-grained quartz and white mica (sericite) develop and much of the hydrous iron oxide is reduced and combined to chlorite, siderite or pyrite.

### The Chemical Sediment.

The solutions consequent upon the breaking down or weathering of rocks are in part redeposited in the mechanical sediments as cements in part precipitated in other rocks, but much of it is carried away to rivers, lakes or oceans, and there may form deposits.

If these form without the assistance of organisms, vegetable or animal, they are known as chemical sediments.\*

The "rocks" which are chemical sediments are chiefly anhydrite, gypsum and halite or rock salt; locally there are other deposits such as the potassium deposits of Stassfurt, the soda nitre of Chili and various borates which have geological significance.

### Sediments Due to Organisms.

These include:

1. The inorganic portion of skeletons of animals and plants consist mostly of carbonate of lime, some of phosphate of lime, some of silica.
2. The organic substance usually of plants, partly of animals, such as coal or petroleum.
3. Living and dead organisms may act to precipitate sediments, as when plants expel  $\text{CO}_2$  and become coated with  $\text{CaCO}_3$  or albumen generates ammonium carbonate, precipitating  $\text{CaCO}_3$ .

The "rocks" belonging to this division are the limestones and dolomites, the phosphate rock, coal and some silica deposits such as diatomaceous earth.

### Metamorphic\* Rocks.

Both igneous and sedimentary rocks are greatly altered by the intense horizontal pressures which cause rock folding or mountain making. Not only is a lamellar structure developed but under the pressure and resultant heat the circulating waters effect recrystallizations and molecular rearrangements "in place" usually with decrease of volume, that is, denser minerals. Often water is introduced as in amphibole, chlorite and mica.

The resultant rocks are essentially alike whether formed from igneous or sedimentary rocks.

Quartzites form from sandstone and from silica precipitated by organic matter from shales. Mica schists form from shales, sandstones, etc.

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\* While strictly any change in composition or structure is generally reserved for strongly marked changes such as those in metamorphic rocks.

Hornblende schists or amphibolites form from basic igneous rocks rich in pyroxene; chlorite schists form from rocks rich in iron and alumina silicates. Gneisses form from different igneous and sedimentary rocks.

## B. THE MINERALS FORMED DURING THE COOLING OF A MAGMA.

### 1. The Minerals which Separate from the Liquid Magma.

The average composition\* of igneous rocks is not greatly different from that already given p. 239 for the average composition of the crust of the earth.

In any given magma many possible combinations exist, and the same magma, solidifying under different conditions, may yield different minerals.

In general all the K, Na and Ca and most of the Mg, Al and Fe unite with oxygen and silicon to form silicates. Excess of Si separates as  $\text{SiO}_2$  and relatively small amounts of Fe and Al form oxides, ferrates and aluminates and Mg may combine as an aluminate.

Experience shows that the number of minerals which actually form is greater in the medium basic magmas than in the highly siliceous or very basic magmas.

Taking an average of some 700 described igneous rocks, Clarke estimates that a few great groups constitute an overwhelming proportion, although in particular instances other groups may dominate. He gives as the proportions:

|   |                |
|---|----------------|
| 1. The feldspars . . . . .                | 59.5 per cent. |
| 2. The pyroxenes and amphiboles . . . . . | 16.8 " "       |
| 3. Quartz . . . . .                       | 12.0 " "       |
| 4. The micas . . . . .                    | 3.8 " "        |
| 5. Accessory minerals . . . . .           | 7.9 " "        |
|   | 100.0 " "      |

In addition to the great groups mentioned other important primary minerals in certain igneous rocks are:

*The Feldspathoids*, nephelite, leucite, sodalite, haüynite, noselite.

*The Chrysolite Group*. Chrysolite, fayalite, etc.

*Tourmaline and topaz* in regions near pneumatolytic action.

*Garnet* in its varieties pyrope, andradite, almandite and spessartite.

*Corundum and spinel* in rocks rich in alumina.

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\* On basis of 1,000 to 1,500 analyses O 47.05, Si 28.26, Al 7.98, Fe 4.47, Ca 3.43, Mg 2.34, Na 2.54, K 2.50. Of the remaining 1.43 per cent. Ti 0.45, H 0.16, C 0.13, P 0.11, S 0.11, Ba .097. Clarke, Bulletin 491, U. S. Geol. Survey, p. 27.

† Ibid., p. 31.

*The Accessory or Minor Primary Minerals.*—Certain minerals are sometimes present in igneous rocks in small amounts among which are:

*Elements*, graphite, diamond, iron, copper, gold, platinum.

*Sulphides*, pyrrhotite, pyrite, pentlandite, molybdenite, millerite.

*Oxides*,\* magnetite, hematite, ilmenite, chromite, rutile, brookite, hausmannite, cassiterite.

*Silicates*, allanite, analcite, iolite, sillimanite, titanite, zircon.

*Sundries*, apatite, calcite, fluorite, monazite.

## 2. Pegmatite Veins and their Minerals.

Igneous rocks are often cut by dikes or veins consisting chiefly of coarse and even gigantic crystals of the common minerals of the igneous rock, and usually a large number of other minerals which are in part the accessory minerals of the igneous rock, in part minerals containing the same elements combined with water, fluorine, chlorine, boron and in part combinations of elements not observed in the igneous rock. Crystal druses are frequent.

These veins are believed to represent a late stage of solidification in which the magma, thinned both by the loss of the already solidified minerals and by the release of the volatile substances dissolved therein under pressure, penetrates cracks both in the solidified portion and in the surrounding rock.

### The Minerals of Pegmatites.

While there are pegmatites of most of the plutonic rocks the granitic pegmatites and the elaeolite-syenite pegmatites are most important and contain the greatest variety in minerals.

*In granitic pegmatites* the typical species which often develop as large or giant crystals are feldspars (chiefly orthoclase and microcline, often intergrown with albite), quartz, mica (chiefly muscovite or lepidolite, less biotite), tourmaline (dark in compact rock often colored in the druses), spodumene, and beryl.

Very widely distributed species are apatite, zircon, titanite, fluorite, topaz, rutile, monazite, columbite.

Where the vein penetrates other rock it may take up constituents therefrom and develop such minerals as garnet, andalu-

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\* Ferrates, chromates, etc., included.

† In certain localities Weinschenck describes pegmatites due to rock pressure, these lack the crystal druses and may be dense mica-like masses with enclosed large crystals such as the Lisens andalusite and the enormous 25 m. long quartz of Zillerthal.

site, zoisite, phlogopite, sillimanite, cyanite, staurolite, iolite, spinel, corundum, possibly diamond.

Minor minerals in granite pegmatites are allanite, amblygonite, brookite, cassiterite, chrysoberyl, euclase, fergusonite, gadolinite, graphite, ilmenite, magnetite, molybdenite, petalite, phenacite, samarskite, triphylite, uraninite.

**In Nepheline-Syenitic Pegmatites** the great minerals are the soda feldspars, albite and anorthoclase, the soda pyroxenes, acmite and ægirite, the soda amphiboles barkivikite and arfvedsonite, nephelite, sodalite, concrinite, zircon.

In addition there are a host of rare silicates, titanites, zirconates, columbates, tantalates and other compounds of both common and rare elements.

A few of these species are astrophyllite, eudialyte, euxenite, lävenite, mosandrite, polycrase, pyrochlore, rinkite, thorite, wöhlerite.

In still other varieties of pegmatites there may be developed large crystals of apatite, wernerite, labradorite, hypersthene, green hornblende, pyroxene, rutile.

The economically important minerals of the pegmatites are numerous and include not only quartz, feldspar and mica but cassiterite, wolframite, the minerals of yttrium and thorium, zircon, apatite, and the lithium minerals.

### 3. Magmatic Segregations and their Minerals.

The eruptive rocks of a district may have such chemical characters in common and such gradations into one another as to indicate that they are due to splitting up or "differentiation" of one homogeneous rock magma into several by the segregation of certain constituents. It is believed that the changes take place chiefly before the magma is forced up.\*

#### The Minerals of Magmatic Segregations.

The minerals which segregate are the minerals which first crystallize, that is:

*Oxides*, magnetite, ilmenite, chromite, corundum, rutile, cassiterite.

*Sulphides*, pyrrhotite, pentlandite, chalcopyrite, pyrite, molybdenite.

*Elements*, iron, platinum, copper, gold.

The rocks involved are chiefly basic gabbro, peridotite, norite, occasionally acidic granite.

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\* The high specific gravity 5.6 of the earth as a whole in comparison to 2.7 to 2.8 for its crust suggests an interior segregation of the heavier materials near the center.



#### 4. Zeolites.

The formation of zeolites, in the cavities in basic lavas, pegmatite dikes and ore veins is probably the last phase of consolidation of a magma. Their rarity in veins suggests the need of stagnant waters. The process is not well understood and is intimately connected with the method of formation of metallic copper.

The best known zeolites are: heulandite, stilbite, laumontite, chabazite, analcite, natrolite, thomsonite.

#### 5. The Minerals formed near Volcanoes.

These rising vapors act on the sides of the crevices and react upon each other, producing many minerals in small amounts, the principal groups being:

Sulphur by the reaction  $\text{SO}_2 + 2\text{H}_2\text{S} = 3\text{S} + 2\text{H}_2\text{O}$ .

Oxides\* by the decomposition of chlorides at high temperature.

Carbonates by the action of  $\text{CO}_2$  on the oxides.

If the flowing lava passes over vegetable matter sal-ammoniac ( $\text{NH}_4\text{Cl}$ ) is formed.

Chlorides and sulphates may form by action of the vapors on the adjacent rocks. A. Scacchi gives a large list but those in quantity at Vesuvius are chiefly alunite and gypsum.

Other minerals are, amphibole, tourmaline, topaz, phlogopite, chondrodite, vesuvianite, epidote, fluorite.

The hot solutions near extinct volcanoes often produce at and near the surface *potash minerals*, sericite, adularia, alunite and other species such as gypsum, jarosite, fluorite, barite, calcite, chlorite, epidote.

#### C. THE MINERALS PRODUCED BY WEATHERING AND THE WEATHERING SOLUTIONS.

These may be considered as constituting the following "Occurrences":†

6. The Mechanical Sediments.

7. The Chemical Sediments.

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\* A crack in lava at Vesuvius in 1817 was filled in 10 days with a 3-ft. thick deposit of hematite.

† The gossans or oxidized portions of ore deposits are due to the weathering solutions but are considered later.

## 8. The Sediments of Organic Origin.

As previously stated, p. 244, part of the weathering solutions penetrate and join the underground water.

## 6. The Minerals of the Mechanical Sediments.

The minerals will be either

(a) Minerals in fragments of the original rock.

(b) New minerals.

The minerals from the original rock need not be listed except to say that a few species dominate such as quartz, feldspars and micas. The accessory minerals, magnetite, zircon, corundum, ilmenite, chromite, tend to accumulate.

### The New Minerals.

Comparatively few form, the principal ones being

Hydrous aluminum silicates of the kaolin group often colloidal.

Colloidal silicic acid yielding opal, chalcedony or chert.

Iron hydroxides probably in colloidal condition.

Sericite (white muscovite) from feldspar.

Rutile, possibly from titanitic acid in colloids.

*If the decomposition is partial there will be intermediate products.*

Albite and anorthoclase from more basic feldspars.

Chlorite from hornblende, biotite, pyroxene.

Epidote from feldspar.

Serpentine\* from chrysolite, enstatite, pyroxene, hornblende.

Talc from pyroxene, amphibole, enstatite.

Magnetite from chrysolite, biotite.

Amphibole from pyroxene.

*Under peculiarly favorable circumstances the silica may be carried away, leaving bauxite, gibbsite, limonite or other hydroxides.*

## 7. The Minerals of the Chemical Sediments.

The deposition of minerals from weathering solutions may take place from springs or running streams or in marshes, lakes, seas or ocean.

### The Minerals Deposited by Springs.\*

Although all springs contain mineral matter the water is often merely rain water which has followed a comparatively short

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\* Clarke classifies them as chloride waters, sulphate waters, carbonate waters, silicious waters, nitrate, phosphate and borate waters, acid waters. Bulletin 491, U. S. Geol. Survey, p. 190.

course through the soil and emerged at a lower elevation. It contains little more than the dissolved gases from the atmosphere. Other springs, particularly thermal springs and geysers with temperatures independent of the season of the year, may contain sufficient dissolved material to deposit solids on emergence or during their passage underground. The principal deposits obtained are:

*Carbonates*, calcite, aragonite, siderite, hydrozincite, hydrodolomite (stalactites, calc sinter, tufa, and flos ferri are of this type).

*Silica*, opal, quartz, chalcedony.

*Sulphides and Sulphur*, cinnabar, realgar, orpiment, stibnite, galenite, sulphur.

*Other Deposits*.—Sassolite, scorodite, fluorite, celestite, the alums, halloysite, siderite, and limonite.

### The Minerals Deposited by Running Streams.

The dissolved material of rivers and streams consists essentially of carbonates, sulphates and chlorides of calcium, sodium, magnesium and potassium and considerable silica. Before reaching the ocean most of the silica, carbonic acid and calcium, and about half of the potassium disappear.\* Definite mineral deposits are rare; the mud at the bottom is clay like. Sometimes there are deposits of travertine.

### The Minerals formed in Oceans.

Some deposits of calcium carbonate and of dolomite are believed to be chemical sediments. Glauconite forms just beyond the wave

\* For comparison of mineral components the general average for river and lake waters and the mean of 77 analyses of ocean water collected by *Challenger* expedition are here given: *Bull. U. S. Geol. Surv.*, 491, p. 106.

|  | River and Lake. | Ocean. |
|--|-----------------|--------|
| CO <sub>2</sub> .....                    | 35.15           | 2.07   |
| SO <sub>4</sub> .....                    | 12.14           | 7.69   |
| Cl.....                                  | 5.68            | 55.29  |
| Br.....                                  | —               | .18    |
| NO <sub>3</sub> .....                    | .90             |        |
| Ca.....                                  | 20.39           | 1.20   |
| Mg.....                                  | 3.41            | 3.72   |
| Na.....                                  | 5.79            | 30.59  |
| K.....                                   | 2.12            | 1.11   |
| (FeAl) <sub>2</sub> O <sub>3</sub> ..... | 2.75            |        |
| SiO <sub>2</sub> .....                   | 11.67           |        |

action and the other important iron silicates, greenalite, chamosite and thuringite, are supposed to have a similar origin.

The proportion of dissolved solids in the ocean is only 33 to 37 in the 1,000. Deep sea dredgings bring to light principally a red clay containing minute crystals of a rare zeolite called phillipsite, nodules of hydrated oxide of manganese and iron and some enstatite, all apparently resulting from the decomposition of a lava.

For the dissolved constituents to separate there is needed a concentration of the solution, usually a land-locked basin with a shallow bar between it and the sea.

The usual formation consists of beds of anhydrite, gypsum and halite. After their separation the mother liquor contains chiefly sulphates and chlorides of potassium and magnesium. These usually escape; in fact, only one great deposit is known, that of Stassfurt and Leopoldshalle, south of Magdeburg, Prussia.

It has been theorized that the raising of the bar converted the basin into a salt lake from which further evaporation occurred, giving successively kieserite, carnallite and by secondary reactions kainite, sylvite, boracite and a series of other species.

#### **Minerals formed in Lakes.**

In some lakes calcium minerals are rare and the deposits are chiefly halite and other soda minerals such as mirabilite, natron and trona. In others which have probably received boric acid from hot springs the boron minerals are prominent especially borax and ulexite. Other carbonates, sulphates and chlorides are also present.

### **8. The Minerals of the Sediments due to Organisms.**

*Aragonite and Calcite. By Action of Animals.*—Where marine life is abundant  $\text{CO}_2$  is the principal gas in the sea water; similarly when organic decay is in progress ammonium carbonate is formed. The shells and frameworks are in part aragonite, in part calcite.

*By Action of Plants.*—Algae chara, mosses and many aquatic plants absorb the  $\text{CO}_2$  and thus become coated with  $\text{CaCO}_3$ , forming sinter or travertine, which may later be compacted by further deposition of  $\text{CaCO}_3$ . Fresh water marls also are in part due to action of plants.

*Dolomite.* In marine sediments magnesium carbonate tends to accumulate, while the more soluble calcium carbonate is dissolved.

Coral in the living animal is aragonite. Coral rock may be essentially dolomite, the lime being removed and replaced by magnesia from the sea.

*Magnesite.*

*Limonite* (bog ore) is in part due to one of the algæ.

*Silica* taken from ocean water by sponges, radiolaria, etc., forms banks of hornstone. Diatoms in marshes yield great beds of soluble silica. Algæ in hot springs precipitate geyserite.

*Sulphur* is separated from sulphates by certain algæ and bacteria, and by decomposing organic matter.

*Pyrite*, *marcasite* and some other sulphides are precipitated from solutions by decomposing organic matter.

*Phosphates*.—The marine deposits of bone shell and animal matter by relatively more rapid solution of the carbonates form phosphate nodules and by later changes form the large deposits of phosphate.

*Soda Nitre* and *Nitre* may be regarded as due to nitrifying organisms.

#### D. METAMORPHIC MINERALS AND VEIN MINERALS.

##### 9. The Minerals of Contacts.

Contact metamorphism occurs when an igneous rock penetrates another rock and is a pneumatolytic process involving heat, pressure, and the mineralizing vapors given off by the intrusive rock, chiefly steam and often fluorine, boric acid, etc. The textures of both rocks change and new minerals form, at the contact and for some distance from it.

The action is largely a rearrangement of the same material into new compounds with little total chemical change. This is most marked in the country rock. In the igneous rock the attempt of the vapors to escape may form the minerals of the pegmatites such as tourmaline.

The zone of contact will vary from a few inches to a mile in width.

##### Granite Contact with Limestone.

An impure siliceous limestone in contact with an eruptive granite would probably be converted into a granular marble\* containing crystals of silicates, chiefly calcium-bearing but varying with the impurities in the limestone.

Very characteristic species are garnet (chiefly grossularite), vesuvianite, amphibole (especially tremolite, also actinolite, hornblende, pargasite), pyroxenes (especially diopside, also fassaite), wollastonite, wernerite, epidote, biotite, and tourmaline (especially brown varieties).

If magnesia is plentiful there may form: spinel, brucite, and

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\* The more silica present the more CO<sub>2</sub> will be displaced.

the silicates, forsterite, chrysolite, enstatite, hypersthene, and their alterations, talc and serpentine.

Carbonaceous material forms graphite. Minor minerals are rutile, fluorite, zircon, monazite, lapis lazuli.

**Contacts with Argillaceous Rocks.** (Clays, shales and slates.)

Near the contact the rocks are baked to a dense hornfels which *under the microscope* may show many minerals; further out this grades into schists.

The most characteristic species are:

*Micas* especially biotite. Andalusite (chiastolite), frequently sillimanite and sometimes cyanite, staurolite, tourmaline and iolite. *Amphibole* (hornblende). *Feldspars*—anorthite, albite, etc. *Quartz*.

Accessories are rutile, graphite, spinel, corundum.

Contact metamorphism will effect similar changes in other mineral deposits, sandstones, beds of anhydrite, gypsum or siderite or even basic eruptive rocks.

There may be almost fusion near the intrusive mass and in such a case the metamorphic minerals may pass back to igneous minerals, for instance, amphibole to chrysolite and pyroxene.

## 10. The Minerals Formed in Regional Metamorphism.

The chemical changes due to intense pressure from rock folding, circulating waters often hot and charged with many constituents including the so-called mineralizing agents are very complex,\* many new minerals form often denser† than the originals and many with constitutional water,‡ basic feldspars tend to form more acid varieties, pyroxene to change to amphibole and amphibole to chlorite or conversely micas and chlorite may form feldspars and hornblende.

After the crushing has ceased, as shown by the fact that they are not crushed, porphyritic crystals of anhydrous minerals develop

\* Clarke sums up the reactions producing chemical changes in metamorphism as molecular rearrangement, hydration, dehydration, oxidation, reduction; other changes by percolating solutions, and by gases and vapors, changes by igneous intrusives.

† Largely molecular rearrangements giving decreased volume, e. g., plagioclase and orthoclase to albite, zoisite, muscovite, quartz with loss of 15 per cent. volume.

‡ Micas, chlorites, epidotes, etc.

of higher density than the average of the rock. No simple list can be made, the material and the reactions being too varied.

Minerals often developed porphyritically are garnet, staurolite, andalusite, iolite, albite, rutile, tourmaline, pyroxene, amphibole, ilmenite, apatite, magnetite, topaz, biotite, titanite.

Other common or locally very prominent species are: sillimanite, cyanite, the micas (phlogopite, biotite, muscovite), other feldspars, the chlorites, epidote, zoisite, and piedmontite, serpentine and talc, wollastonite, wernerite, corundum, beryl and chrysoberyl, graphite.

Important ore bodies, especially\* in iron, manganese and zinc may be products of metamorphic action.

\* Minor species are vesuvianite, prehnite, zircon, hematite, monazite, gibbsite, pyrophyllite, spinel.

## 11. The Minerals of Veins and Replacements.

In all classes of rocks there are numerous fissures and cavities into which the underground water can penetrate. Many of these have been filled by minerals deposited from these waters.

Veins strictly are tabular or sheet-like masses filling crevices or fissures. Technically they are called "mineral veins" only when they contain ores. More irregular bodies called stocks, beds, lenses, occur which may sometimes owe their shape to the filling of irregular cavities but more often to a solution and replacement of the original minerals of the country rock (see p. 246). Frequently also deposits occur which are not so definitely† connected with veins and yet evidently are complete or partial replacements of a rock such as limestone by a new mineral.

For instance, the *Cleveland oolitic iron ore* is oolitic carbonate of iron which has replaced oolitic limestone; and the manganese deposits of the Thuringer Wald are manganese ores which have replaced everything but the quartz of a porphyry.

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\* For instance, Weinschenk gives as accessories in the crystalline schists:

Oxide ore bodies, magnetites like Oravitz, manganese oxides like Langban, manganese zinc deposits, like Franklin, magmatic concentrations in gneiss or eruptives.

Sulphide ore bodies—pyrrhotite, pyrite, chalcopyrite, sphalerite, galenite.

Carbonate ore bodies—siderite usually in limestone.

Emerald in granular limestone, Naxos, and in mica schist, Chester, Mass.

† Replacements are usually connected with some channel or fissure through which the aqueous or gaseous solutions may have entered.

The minerals of veins by their composition and arrangement are shown to be deposits from solution, but in most cases not simply solutions of the neighboring rocks in the underground water but also solutions in the vapors of deep-seated magmas. Veins with metallic contents being usually connected with some intrusion of igneous rock.

As the vapors rise into regions of lower pressure and temperature condensation takes place, fluid solutions form, various species separate and are deposited on the walls and may ultimately fill the fissure, forming a vein.

The minerals formed in this way are usually divided into ores\* and gangue minerals and a complete list would include most of the species described in this book. The following lists give some idea of relative frequency.

*Primary Ores.* The great ores are pyrite, galenite, sphalerite, and chalcopyrite. These frequently carry valuable amounts of silver, gold, copper, nickel.

Common in veins also are arsenopyrite, stibnite, tetrahedrite, chalcocite, native gold, gold tellurides (calaverite, sylvanite, petzite, etc.). Rich silver minerals—argentite, polybasite, proustite, pyrargyrite, stephanite.

Others are, smaltite, cobaltite, niccolite, millerite, braunite, hausmannite, rhodochrosite, bornite, enargite, etc.

*Gangue Minerals.*—The great gangue mineral is quartz (or sometimes the silica is chalcedony or opal or both) and following this are calcite, dolomite, siderite and other carbonates, fluorite, barite.

Locally common † are rhodonite, rhodochrosite and orthoclase (valencianite), roscoelite. Others are zeolites, chlorite, axinite, ‡ celestite.

### High Temperature Veins.

Certain deposits appear from their minerals and the changes in the country rock to have formed at higher temperatures and

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\* Ores are minerals containing desired elements. Gangue minerals are all other minerals in the deposit. The minerals formed from the ascending waters may be called primary, those formed later secondary.

† Tonopah, Nev., Pachuca, Mex., Butte, Mont., Silverton, Col.

‡ Kongsberg, Norway.



pressures and with so decided pneumatolytic action that their minerals suggest those of a pegmatite.

The most important group of these are the tin veins which grade into wolframite or molybdenite veins and with them Lindgren classes\* certain veins of gold quartz and gold telluride (Australia) and certain veins of copper, lead and cobalt characterized by association with tourmaline.

*The characterizing gangue minerals of such deposits are:*

Tourmaline, biotite, garnet, fluorite, topaz, pyroxene, amphibole, apatite, ilmenite, magnetite, mica, spinel, feldspar (usually albite), lithia mica.

*The ore minerals of tin veins* are fairly constant and include cassiterite, molybdenite, wolframite, scheelite, bismuth, bismuthinite, arsenopyrite and minor amounts of the common sulphides, pyrite, pyrrhotite, chalcopyrite, galenite, sphalerite.

### **Secondary Vein Minerals.**

Veins, like the rock in which they occur, undergo changes. Near the surface there is oxidation and solution, lower the solutions may yield up their contents, forming an economically very important "zone of secondary enrichment," below this again will be the unaltered ore, often very much poorer in the desired constituent than the enriched zone above it.

Important secondary ores are:

*Iron.* Limonite (often forming the principal metallic mineral in the upper part of a vein), hematite, vivianite.

*Silver.* Rich silver minerals as secondary enrichments and native silver, cerargyrite, bromyrite, embolite, iodyrite in the upper portions.

*Copper.* Chalcocite, covellite, cuprite and bornite as secondary enrichments, malachite, azurite, copper, chrysocolla, chalcantite, brochantite in upper portions.

*Gold.* Native gold both as secondary enrichment and in upper portions.

*Lead.* Cerussite, anglesite, pyromorphite, mimetite, crocoite, vanadinite, wulfenite.

*Zinc.* Smithsonite, calamine.

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\* "Mineral Deposits," 611.

## CHAPTER XVIII.

### THE MINERALS OF METALLIFEROUS ORE DEPOSITS.

The order\* in which the minerals are described is chiefly based on their economic uses as in the former editions but more groups have been made, each group consisting of the chief minerals containing some economically important element, its ores and possible ores, and the more common alteration products.

To place each group in its right perspective its economic and genetic relations are discussed under the headings Economic Importance and Formation and Occurrence. These group discussions are followed by the descriptions of species.

In discussing formation and occurrence four great groups\* of deposit are usually made.

- I. Magmatic segregations, p. 251.
- II. Contact deposits, p. 256.
- III. Veins and replacements, p. 258.
- IV. Sedimentary deposits, p. 252, including placers, residual deposits, chemical sediments and some deposits of doubtful genesis.

In descriptions where possible details previously given under the descriptions of these occurrences will be omitted.

### THE IRON MINERALS.

The minerals described are:

|                   |                    |  |              |
|-------------------|--------------------|--|--------------|
| <i>Metal</i>      | <i>Iron</i>        | <i>Fe</i>  |              |
| <i>Sulphides</i>  | <i>Pyrrhotite</i>  | $\text{Fe}_{7-9}\text{S}_{11-13}$                                  | Hexagonal    |
|                   | <i>Pyrite</i>      | $\text{FeS}_2$   | Isometric    |
|                   | <i>Marcasite</i>   | $\text{FeS}_2$   | Orthorhombic |
| <i>Oxides</i>     | <i>Magnetite</i>   | $\text{Fe}_3\text{O}_4$  | Isometric    |
|                   | <i>Hematite</i>    | $\text{Fe}_2\text{O}_3$  | Hexagonal    |
|                   | <i>Ilmenite</i>    | $\text{FeTiO}_3$   | "            |
| <i>Hydroxides</i> | <i>Turquoise</i>   | $\text{Fe}_2\text{O}_3(\text{OH})_2$                               |              |
|                   | <i>Goethite</i>    | $\text{FeO}(\text{OH})$  | Orthorhombic |
|                   | <i>Limonite</i>    | $\text{Fe}_2(\text{OH})_4\text{Fe}_2\text{O}_3$                    |              |
| <i>Sulphates</i>  | <i>Copiapite</i>   | $\text{Fe}_3(\text{FeOH})_2(\text{SO}_4)_4 + 18\text{H}_2\text{O}$ | Monoclinic   |
|                   | <i>Melanterite</i> | $\text{FeSO}_4 + 7\text{H}_2\text{O}$                              |              |

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\* "Beyschlag Vogt and Krusch." Truscott's translation, Vol. 1, p. 240.

|           |            |  |            |
|-----------|------------|--|------------|
| Phosphate | Vivianite  | $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$ | Monoclinic |
| Carbonate | Siderite   | $\text{FeCO}_3$  | Hexagonal  |
| Silicates | Chamosite  | Hydrous iron aluminum silicate                         |            |
|           | Thuringite | " " "  | "          |

Other iron minerals elsewhere described are arsenopyrite, franklinite, chromite, columbite, wolframite, fayalite, as well as many iron-rich varieties of pyroxene, amphibole, garnet, mica, etc.

#### ECONOMIC IMPORTANCE.

The iron minerals have important and varied uses, which may briefly be described under the following heads:

- I. In natural state.
- II. As ores of iron.
- III. As ores of sulphur and iron.

#### I. Uses in Natural State.

In 1914 the production of ocher, umber and sienna and natural oxide paints was 51,495 short tons.\* Limonite and hematite are the principal natural oxides ground for paint.

#### II. Minerals Used as Ores of Iron.

In the United States the minerals smelted for iron are, in order of quantity used,† hematite, limonite, magnetite, and siderite. Goethite and turgite are commercially included with limonite under the name brown hematite, and some ilmenite is smelted with other ores. The residues from the roasting of pyrites are sometimes used as a source of iron.

In 1915 the United States produced 58,843,804‡ long tons of iron ore, about four fifths of which came from the Lake Superior region of Michigan, Wisconsin and Minnesota, and about one eighth came from the Southern States.

The greater portion of the iron ore mined in the world each year is converted into *pig iron*. That is, the ore is deprived of its oxygen by the action of incandescent carbon and the hot reducing

\* *Mineral Resources U. S.*

† Ernest F. Burchard, in *Mineral Resources of United States, 1914*, gives as amounts mined for 1914: Hematite, 38,286,670 long tons; limonite and goethite, 1,537,750 long tons; magnetite, 1,610,203 long tons; siderite, 5,138 long tons. The total production for 1914 being one-third less than either 1913 or 1915.

‡ *Engineering and Mining Journal*, 1916.

gases resulting from its combustion, and becomes a liquid mass of metallic iron, combined and mixed with a little carbon, silicon, phosphorus, sulphur and other impurities. The furnace used is a vertical shaft, everywhere circular in horizontal section, but usually widening from the top downwards to a certain level, and then again narrowing to the hearth. Hot air is forced into the furnace through nozzles called tuyeres, entering just above the hearth.

The ore and fuel are analyzed and some flux is added, which, when combined with the ash of the fuel and the foreign ingredients of the ore, forms a definite silicate of known fusibility, called the slag. The temperature of the furnace differs at different levels, but is practically the same at all times at any one level.

The ore, charged at the top, in alternate layers with fuel and flux, passes through zones of different temperature as it descends, and is reduced, carburized, fused, and flows into the hearth. The slag forms in a definite zone after the complete reduction of the iron, and falls also to the hearth, but, being lighter, floats on the melted iron until drawn off. From time to time the metal is run out into sand moulds, forming the pigs or *pig iron*, of which 29,971,191\* long tons were produced in the United States in 1915.

This pig iron, by various processes, is converted into wrought iron, cast iron and steel.

### III. Minerals Used as Ores of Sulphur and Iron.

Pyrite, and, to a less extent, marcasite and pyrrhotite, are very extensively used in the manufacture of sulphuric acid. In 1914,† 1,363,279 tons were so used in the United States, of which 336,662 were domestic, 1,026,617 imported. The sulphides are burned in furnaces with grates, and the gases are converted into sulphuric acid. The residues, in addition to iron, frequently contain copper, nickel or gold, which are extracted later.

#### FORMATION AND OCCURRENCE OF THE MINERALS OF IRON.

The iron minerals occur in all four classes of deposit.

#### Magmatic Segregation.

*Titaniferous magnetite*‡ and *ilmenite*, in basic rocks.

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\* *Loc. cit.*

† *Mineral Industry*, 1914, p. 692.

‡ In many cases this is a microscopic mixture of pure magnetite and ilmenite which may be separated by magnetic concentration. Beyschlag Vogt and Krusch, p. 254.

As at Ekersund-Soggendal, Norway; Taberg, Sweden; Saguenay River and St. Paul's Bay, Canada; and Elizabethtown and Sandford Lake, Adirondacks, N. Y.

*Magnetite* from acid magmas with some *hematite*, both free from titanium.

This includes the enormous Swedish *magnetite* deposits such as K runavaara, Gellivare, etc., and others in Norway.

*Pyrrhotite* in the *nickel-pyrrhotite* deposits of Canada, Norway, Sweden and Piedmont *pyrite* sometimes being prominent.

*Pyrite* in the great intrusive pyritic deposits, such as Rio Tinto, Spain; Agordo, Italy; Bodenmais, Bavaria; Sain Bel, France. Possibly Fahlun, Sweden. Some authorities\* regard the greatest of these to be magmatic segregations.

#### Contact Deposits.

*Hematite* of Elba and the *magnetite* and *hematite* of Christiania, Sweden; Banat, Hungary; and "practically every known iron deposit along the Pacific coast from Alaska to southern Chili."†

*Pyrrhotite* and *pyrite* as at Traversella, Piedmont; Ducktown, Tenn.‡

#### Veins.

*Pyrite*, *marcasite*, *pyrrhotite* and *siderite* all occur as vein minerals, *pyrite* much more frequently than the others.

#### Replacements.

*Limonite* replacing limestone is common along the Appalachian Mountains and extensively mined in the Southern States.

*Hematite* is often a replacement of limestone as at the great deposit of Ulverstone, Lancashire. The most important examples, are the great Lake Superior deposits§ which consist chiefly of *hematite* but also *goethite* and *turgite* and are be-

\* Beyschlag, Vogt and Krusch. Truscott translation, p. 301.

† Eckel, "Iron Ores," p. 87.

‡ Lindgren, "Mineral Deposits," p. 598.

§ "As first deposited the iron formation consisted of iron carbonate or ferrous silicate (*greenalite*) with some ferric oxide all minutely interlayered with chert forming the ferruginous chert. When these were exposed to weathering the ferrous compounds, the *siderite* and *greenalite*, oxidized to *hematite* and *limonite* essentially *in situ*, although some of it was simultaneously carried away and redeposited. The result was ferruginous chert or jasper, averaging less than 30 per cent. of iron.

lieved to have formed by weathering of lean silicates and carbonates of sedimentary origin and subsequent replacement of silica.

*Siderite* deposits formed by replacement of limestone exist in Cornwall, the Alps and Bohemia.

### Sediments.

*Magnetite* (black sands), or *ilmenite* (iserite).—Transported concentrates.

*Limonite* or *siderite*.—Bog deposits largely precipitated by iron bacteria.

If much carbonic acid or decaying organic matter is present the bog ore formed is *siderite*. If air has free access the bog ore is *limonite*.

*Hematite*, *limonite*, *siderite* and the silicates *chamosite* and *thuringtonite*. "Marine Basin Ores" as deposited in sea basins, usually oölitic. The Clinton oölitic ores are typical.

*Pyrite*, *pyrrhotite* and *marcasite* disseminated or in concretions in limestone, clay, marl and coal as at Meggen and Rammelsberg, Germany.

### Residual.

*Limonite*, *goethite*, etc., left after weathering, p. 247, sometimes *hematite* and colloidal mixtures. The Appalachian ores and the ores of Cuba are types. *Limonite*, formed chiefly by alteration of *pyrite* and *pyrrhotite*. The most important Gossan deposits are in Ducktown District, Tenn., and Great Gossan Lead, Va.

## IRON.

COMPOSITION.—Fe with some Ni, Cr, Co, Mn.

GENERAL DESCRIPTION.—Masses and imbedded particles of white to gray metal, resembling manufactured iron.

CRYSTALLIZATION.—Isometric, several meteoric irons showing minute cubes and cubes modified by {111} and {110}. Some meteorites, especially the Braunau, are single crystals the same cubic cleavage planes extending through the entire lump. Etching frequently develops the crystalline structure as lines or bands at 60° or 90° which are in part due to plates of varying composition and in part to parting planes parallel to {211}.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, steel-gray to iron-

The concentration of the iron to 50 per cent. and over has been accomplished essentially by the leaching of the silica bands from the chert and jasper." C. K. Leith, *Economic Geology*, Vol. 3, p. 276.

black. Streak, metallic gray. H., 4 to 5. Sp. gr., 7.3 to 7.8. Strongly attracted by the magnet. Tough and malleable. Fracture, hackly.

**BEFORE BLOWPIPE, ETC.**—Infusible. Soluble in acids. In borax or salt of phosphorus, reacts only for iron.

**REMARKS.**—Iron is found sparingly in eruptive rocks, especially basalts, usually in minute grains as at Antrim, Ireland, and in the trap rocks of New Jersey and the dolerite of Mt. Washington, N. H. Masses up to the size of a walnut are found in the basalt of Aschenhübel, Saxony, and masses, one of which weighed fifty thousand pounds, have weathered from the basalt of Oviak, Disco Island, Greenland.

Iron occurs at Chotzen, Bohemia, apparently as the result of the reduction of limonite, and most meteorites are either alloys of iron and nickel or contain such alloys.

### **PYRRHOTITE.—Magnetic Pyrites, Mundic.**

**COMPOSITION.**— $\text{Fe}_x\text{S}_y + z$ .  $\text{Fe}_8\text{S}_7$  to  $\text{Fe}_{11}\text{S}_{12}$ , with frequently small percentages of cobalt or nickel.

**GENERAL DESCRIPTION.**—Usually a massive bronze metallic mineral, which is attracted by the magnet and can be scratched with a knife. Sometimes occurs in tabular hexagonal crystals.

**Physical Characters.** H., 3.5 to 4.5. Sp. gr., 4.5 to 4.6.

LUSTRE, metallic.

OPAQUE.

STREAK, grayish-black.

TENACITY, brittle.

COLOR, bronze-yellow to bronze-red, but subject to tarnish.

Attracted by the magnet.

**BEFORE BLOWPIPE, ETC.**—Fuses readily on charcoal to a black magnetic mass, evolves fumes of sulphur dioxide, but does not take fire. In closed tube, yields a little sulphur. In open tube, gives fumes of sulphur dioxide. Soluble in hydrochloric acid, with evolution of hydrogen sulphide and residue of sulphur.

**SIMILAR SPECIES.**—Pyrrhotite resembles pyrite, bornite and niccolite at times, but differs in being attracted by the magnet and by its bronze color on fresh fracture.

**REMARKS.**—The most important deposit is that at Sudbury, Canada. Others are Kongsberg, Norway; Andreasberg, Harz; Ducktown, Tenn.; Pulaski, Va.; Strafford and Ely, Vt.; Lancaster Gap, Pa. Smaller beds are common.

### **PYRITE.—Iron Pyrites, Fool's Gold.**

**COMPOSITION.**— $\text{FeS}_2$  (Fe 46.7, S 53.3 per cent.), often containing small amounts of Cu, As, Ni, Co, Au.

**GENERAL DESCRIPTION.**—A brass-colored, metallic mineral, frequently in cubic or other isometric crystals or in crystalline masses, which may be any shape, as botryoidal, globular, stalactitic, etc. Less frequently in non-crystalline masses.

FIG. 312.

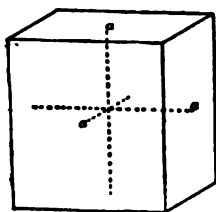


FIG. 313.

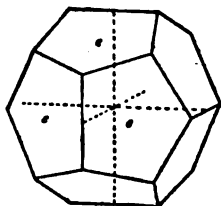


FIG. 314.

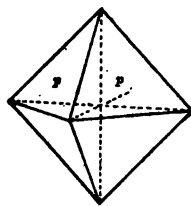


FIG. 315.

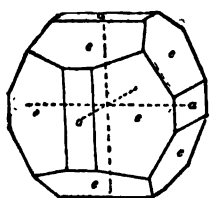


FIG. 316.

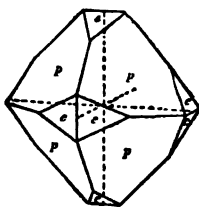


FIG. 317.

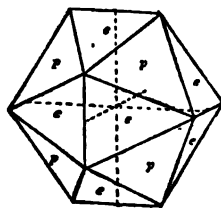


FIG. 318.

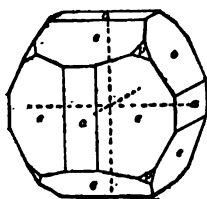


FIG. 319.

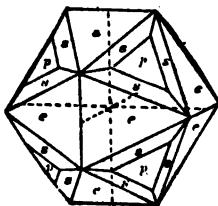
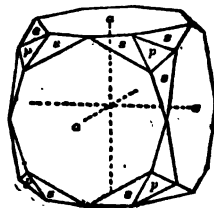


FIG. 320.



CRYSTALLIZATION. — Isometric, class of diploid, p. 65. Most common forms are cube *a*, Fig. 312, and pyritohedron *e*, Fig. 313,  $a : 2a : \infty a$ ;  $\{210\}$  or combinations of these, Fig. 315. The octahedron also occurs alone, Fig. 314, or in combination with *a* and *e*, Figs. 316, 317, 318, and the diploid  $s = (a : \frac{2}{3}a : 3a)$ ;  $\{321\}$  is not rare in combinations, Fig. 319, 320.

The faces of the cube and pyritohedron are frequently striated in one direction parallel to intersections of these two forms.

**Physical Characters.** H., 6 to 6.5. Sp. gr., 4.9 to 5.2.

LUSTER, metallic.

OPAQUE.

STREAK, greenish-black.

TENACITY, brittle.

COLOR, pale to full brass-yellow and brown from tarnish.

BEFORE BLOWPIPE, ETC.—On charcoal, takes fire and burns with a blue flame, giving off fumes of sulphur dioxide, and leaving a



magnetic residue which, like pyrrhotite, dissolves in hydrochloric acid with evolution of hydrogen sulphide. In closed tube, gives a sulphur deposit. Insoluble in hydrochloric acid, but soluble in nitric acid with separation of sulphur.

**SIMILAR SPECIES.**—Pyrite is harder than chalcopyrite, pyrrhotite, or gold. It differs from gold, also, in color, streak, and brittleness. It differs from marcasite chiefly in the fact that its sulphur is more oxidized by the same treatment; for instance, pyrite in very fine powder is *completely* dissolved in about its own bulk of strong nitric acid whereas marcasite leaves some separated sulphur; or if boiled with a solution of ferric sulphate about 52 per cent. of the sulphur of pyrite is dissolved and about 12 per cent. of the sulphur of marcasite.

**REMARKS.**—The uses and occurrence are described p. 263. The most celebrated locality is the Rio Tinto region, in Spain, from which immense quantities of a gold- and copper-bearing pyrite are annually procured. Norway and Germany are large producers. The largest deposits worked in the United States are in Virginia, New York and California. In compact specimens it is not easily altered, but granular masses readily oxidize and are decomposed, forming sulphate of iron and sulphuric acid, thus acting as a vigorous agent in the decomposition of rocks. The final results are usually limonite and sulphates of calcium, sodium, magnesium, etc.

### MARCASITE—White Iron Pyrites.

**COMPOSITION.**— $\text{FeS}_2$ , as in pyrite.

**GENERAL DESCRIPTION.**—Ferric sulphide is dimorphous. Marcasite differs from pyrite in crystalline form, and in little else. It occurs in orthorhombic forms, and in crystalline masses. The compound crystals have given rise to such names as cockscomb

FIG. 321.

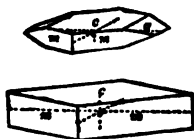
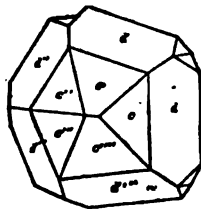


FIG. 322.

FIG. 323.



pyrites, spear pyrites, etc., from their resemblance to these objects. Often, with radiated structure. Color on fresh fracture is usually whiter than in pyrite.

FIG. 324.



Marcasite Twin Crystal. After Lacroix.

CRYSTALLIZATION.—Orthorhombic,  $a:b:c = 0.7662:1:1.2342$ . Crystals usually tabular parallel to base.

Simple forms show unit prism  $m$ , basal pinacoid  $c$  and often one or more brachy domes as  $g = (\infty a:b:\frac{1}{2}c)$ ;  $\{013\}$ . Compound "fivelings" with twin plane  $m$ , Figs. 323 and 324, are frequent.

Supplement angles are  $mm = 74^\circ 55'$ ,  $cg = 22^\circ 21'$ .

**Physical Characters.** H., 6 to 6.5. Sp. gr., 4.6 to 4.9.

LUSTRE, metallic.

OPAQUE.

STREAK, nearly black.

TENACITY, brittle.

COLOR, pale brass-yellow, darker after exposure.

BEFORE BLOWPIPE, ETC. As for pyrite.

SIMILAR SPECIES.—As for pyrite, from which it is only distinguishable by crystalline form, cleavage, and by the slighter effect of oxidizing agents (see pyrite).

REMARKS.—Marcasite is more readily decomposed than pyrite, and is, therefore, an even less desirable constituent in building material, etc. It is found at Cummington, Mass.; Warwick, N. Y.; Joplin, Mo.; Haverhill, N. H.; and in many other localities and is usually mistaken for pyrite.

Well-known foreign localities are the chalk marls near Dover, England, the clay beds near Carlsbad. The Wilkinson Mine of Wisconsin yields it in commercial quantities.

## THE SULPHATES OF IRON.

Decomposing sulphides form sulphates which in dry regions may persist but oftener are dissolved and lost. There are a large series of these of which the best known are

**MELANTERITE.**—Copperas,  $\text{FeSO}_4 + 7\text{H}_2\text{O}$ . A pale green fibrous efflorescence on pyrite or marcasite, or stalactite massive or pulverulent. It has a sweet astringent taste and on exposure it becomes dull yellowish-white.

Found at Copperas Mt., Ohio; Goslar, Hartz; and many other localities.

**COQUIMBITE.**  $\text{Fe}_2(\text{SO}_4)_3 + 9\text{H}_2\text{O}$ . Violet to white or greenish-glassy material often with hexagonal crystals with an astringent taste, often coated with copiapite.

Found as a large bed in trachyte rock at Tierra Amarilla, Atacama, Chili.

**COPIAPITE.**—Misg,  $\text{Fe}_2(\text{FeOH})_2(\text{SO}_4)_3 + 18\text{H}_2\text{O}$ , often with some  $\text{Al}_2\text{O}_3$  or  $\text{MgO}$ . Brownish-yellow to sulphur-yellow, granular, or in loosely compacted crystalline scales, with a disagreeable metallic taste.

Found with coquimbite, also in New Mexico, California, and elsewhere.

For all three the tests are essentially alike. H., 2 to 3, sp. gr., 1.8 to 2.1. Tastes as stated. On charcoal, fuse and become magnetic. Yield water in closed tube and some sulphuric acid. Soluble in water, giving the solution a reaction for sulphuric acid.

**MAGNETITE.**—Lodestone, Magnetic Iron Ore.

COMPOSITION.— $\text{Fe}_3\text{O}_4$  (Fe, 72.4 per cent.) often contains Ti, Mg.

GENERAL DESCRIPTION.—A black mineral with black streak and metallic lustre, *strongly* attracted by the magnet and occurring in all conditions from loose sand to compact coarse or fine grained masses.

CRYSTALLIZATION.—Isometric, usually octahedra, Fig. 325, or loosely coherent masses of imperfect crystals. Sometimes the

FIG. 325.

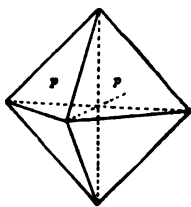


FIG. 326.

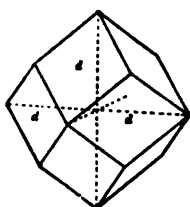
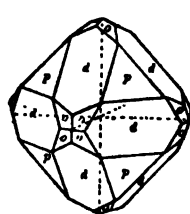


FIG. 327.



dodecahedron *d*, Fig. 326, or a combination of these, Fig. 152, or more rarely with the angles modified by the trapezohedron  $o = (a : 3a : 3a); \{311\}$ . Fig. 327.

Twinning parallel to an octahedral face occurs, sometimes shown by striations upon the octahedral faces.

**Physical Characters.** H., 5.5 to 6.5. Sp. gr., 4.9 to 5.2.

LUSTRE, metallic to submetallic.

OPAQUE.

COLOR and STREAK, black.

TENACITY, brittle.

Strongly attracted by magnet and sometimes itself a magnet (lodestone). Breaks parallel to octahedron.

BEFORE BLOWPIPE, ETC.—Fusible with difficulty in the reducing flame. Soluble in powder in hydrochloric but not in nitric acid.

SIMILAR SPECIES.—No other black mineral is strongly attracted by the magnet.

REMARKS.—The occurrences are described, p. 263.

In this country it is obtained from Pennsylvania, New York, New Jersey and Michigan. Lodestones are obtained mainly from Magnet Cove, Ark.

### HEMATITE.—Specular Iron, Red Iron Ore.

COMPOSITION.— $\text{Fe}_2\text{O}_3$ , (Fe 70 per cent.), often with  $\text{SiO}_2$ ,  $\text{MgO}$ , etc., as impurities.

GENERAL DESCRIPTION.—Occurs in masses varying from brilliant black metallic to blackish red and brick red with little luster. The black is frequently crystallized, usually in thin tabular crystals set on edge in parallel position, less frequently in larger highly modified forms and finally in scale-like to micaceous masses. The red varieties vary from compact columnar, radiated and kidney-shaped masses to loose earthy red material. In *all* varieties the streak is *red*.

CRYSTALLIZATION.—Hexagonal, scalenohedral class, p. 48. Axis  $c = 1.365$ .

The most common forms on the Elba crystals are the unit rhombohedron  $p$  and the scalenohedron  $n = (2a : 2a : a : \frac{1}{2}c)$ ;  $\{22\bar{4}3\}$ . The rhombohedron  $g = (a : \infty a : a : \frac{1}{4}c)$ ;  $\{10\bar{1}4\}$  also

FIG. 328.

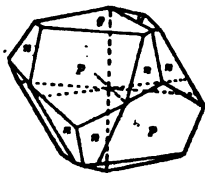


FIG. 329.

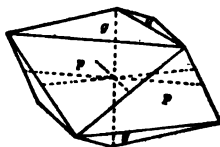
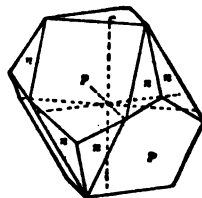


FIG. 330.



occurs. Thin plate-like crystals are the rule at other localities. Sometimes grouped in rosettes, as in the "Eisenrosen," Fig. 331.

Supplement angles. —  $pp = 94^\circ$ ;  $nn = 51^\circ 59'$ ;  $cp = 57^\circ 37'$ ;  $gg = 37^\circ 2'$ ;  $cn = 61^\circ 13'$ .

FIG. 331.



Eisenrosen, Fibia Switz.

FIG. 332.



Radiated reniform, Geikie.

**Physical Characters.** H., 5.5 to 6.5. Sp. gr., 4.9 to 5.3.

LUSTRE, metallic to dull.

OPAQUE.

STREAK, brownish red to cherry red.

TENACITY, brittle un-

COLOR, iron black, blackish red to cherry red.

less micaceous.

Sometimes slightly magnetic.

BEFORE BLOWPIPE, ETC.—Infusible. Becomes magnetic in reducing flame. Soluble in hot hydrochloric acid. In borax reacts for iron.

#### VARIETIES.

*Specular Iron.*—Brilliant micaceous or in crystals. Black in color.

*Red Hematite.*—Submetallic to dull, massive, blackish red to brownish red in color.

*Red Ochre.*—Earthy impure hematite usually with clay. Often pulverulent.

*Clay Ironstone.*—Hard compact red material mixed with much clay or sand.

*Martite.*—Octahedral crystals, probably pseudomorphs.

**SIMILAR SPECIES.**—Resembles at times the other iron-ores and massive cuprite. It is distinguished by its streak and strong magnetism after heating in reducing flame.

**REMARKS.**—As described on p. 264, the greatest hematite deposit is due to concentration and replacement and other great deposits to contact deposits and marine oolitic ores while relatively small amounts are due to magmatic segregation. By far the larger part is obtained from the Marquette and Gogebic ranges of Michigan.

and from the Mesabi range in Minnesota. Smaller but by no means inconsiderable amounts are mined in Alabama and other states.

**ILMENITE.—Menaccanite, Titanic Iron-Ore.**

**COMPOSITION.**— $\text{FeTiO}_3$ , sometimes containing small amounts of Mg or Mn.

FIG. 333.

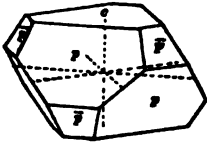
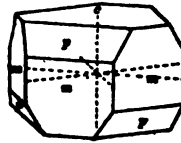


FIG. 334.



**GENERAL DESCRIPTION.**—An iron-black mineral, usually massive or in thin plates or imbedded grains or as sand. Also, in crystals closely like those of hematite in angle.

**CRYSTALLIZATION.**—Hexagonal. Class of third order rhombohedron, p. 54. Axis  $c = 1.385$ . Usually thick plates showing basal pinacoid  $c$ , unit prism  $m$  and unit rhombohedron  $p$ , Fig. 334, or without the prism, Fig. 333. Supplement angles  $pp = 94^\circ 29'$ ;  $cp = 57^\circ 58'$ .

**Physical Characters.**—H., 5 to 6. Sp. gr., 4.5 to 5.

LUSTRE, submetallic.

OPAQUE.

STREAK, black to brownish-red.

TENACITY, brittle.

COLOR, iron-black,

Slightly magnetic.

**BEFORE BLOWPIPE, ETC.**—Infusible in oxidizing flame; slightly fusible in reducing flame. In salt of phosphorus gives a red bead which, on treatment in reducing flame becomes violet, slowly soluble in hydrochloric acid and the solution boiled with tin is violet and on evaporation becomes rose-red.

**SIMILAR SPECIES.**—Differs from magnetite and hematite in the titanium reactions.

**REMARKS.**—As described on p. 263, it occurs as magmatic segregations from basic rocks, also as crystals and grains in igneous rocks and schists and as sand.

**USES.**—It has been used as a constituent of the lining of puddling furnaces and in the making of ferrotitanium.

**GOETHITE.**

**COMPOSITION.**— $\text{FeO}(\text{OH})$ . Fe, 62.9 per cent.

**GENERAL DESCRIPTION.**—A yellow, red or brown mineral, occurring in small, distinct, prismatic crystals (orthorhombic), often flattened like scales, or needle-like, or

grouped in parallel position. These shade into feather-like and velvety crusts. Occurs also massive like yellow ochre.

**PHYSICAL CHARACTERS.**—Opaque to translucent. Lustre, adamantine to dull. Color, yellow, reddish, dark-brown and nearly black. Streak, yellow or brownish-yellow. H., 5 to 5.5. Sp. gr., 4 to 4.4.

**BEFORE BLOWPIPE, ETC.**—Fuses in thin splinters to a black magnetic slag. In closed tube yields water. Frequently reacts for manganese. Soluble in hydrochloric acid.

**USES.**—Goethite is an ore of iron, but is commercially classed with limonite under the name of brown hematite. Large ocherous deposits in Minnesota.

#### **TURGITE.—Hydrohematite.**

**COMPOSITION.**— $\text{Fe}_2\text{O}_3(\text{OH})_2$ , Fe = 66.2 per cent.

**GENERAL DESCRIPTION.**—Nearly black, botryoidal masses and crusts resembling limonite but with a red streak and often with a fibrous and satin-like appearance on fracture. Also bright red earthy masses. Usually associated with limonite or hematite.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, submetallic to dull. Color, dark reddish-black in compact form, to bright red in ocherous variety. Streak, brownish red. H., 5.5–6. Sp. Gr., 4.29–4.68.

**BEFORE BLOWPIPE, ETC.**—Decrepitates violently, turns black and becomes magnetic. Yields water in closed tube with *violent decrepitation*.

**SIMILAR SPECIES.**—Is distinguished from limonite and hematite by its violent decrepitation when heated, its red streak, and its water test.

**REMARKS.**—Like goethite it is frequently mistaken for and classed with limonite. It occurs with limonite at Salisbury, Conn., and in various localities in Prussia and Siberia.

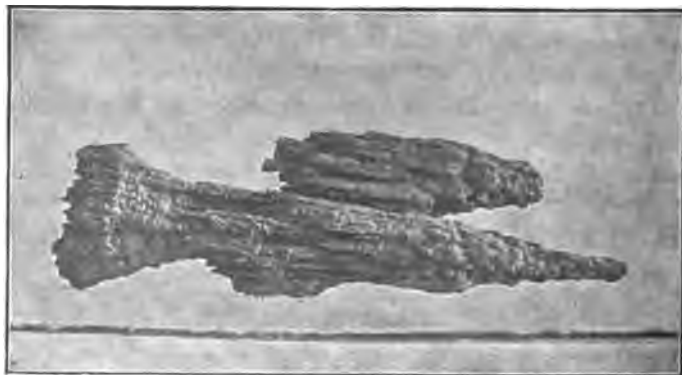
**USES.**—It is an ore of iron but commercially is classed with limonite.

#### **LIMONITE.—Bog-Ore, Brown Hematite.**

**COMPOSITION.**— $\text{Fe}_2(\text{OH})_6\text{Fe}_2\text{O}_3$ , (Fe, 59.8 per cent.). Frequently quite impure, from sand, clay, manganese, phosphorus, etc.

**GENERAL DESCRIPTION.**—Never crystallized, but grading from

FIG. 335.



Stalactite of Limonite, Hungary. Columbia University.

the loose, porous bog-ore and earthy ochre of brown to yellow color and dull lustre; to compact varieties, often with smooth, black, varnish-like surface, but on fracture frequently showing a somewhat silky lustre and a fibrous radiated structure. Sometimes stalactitic, Fig. 335, and often with smooth rounded surfaces and is pseudomorphs. It is frequently found pseudomorphous.

**Physical Characters.** H., 5 to 5.5. Sp. gr., 3.6 to 4.

LUSTRE, varnish-like, silky, dull. OPAQUE.

STREAK, yellowish-brown, TENACITY, brittle, earthy.

COLOR, brown, nearly black, yellow like iron rust.

BEFORE BLOWPIPE, ETC.—In closed tube yields water, and becomes red. Fuses in thin splinters to a dark magnetic slag. Usually reacts for silica and manganese. Soluble in hydrochloric acid, and may leave a gelatinous residue.

#### VARIETIES.

*Bog-Iron*, loosely aggregated ore from marshy ground, often intermixed with and replacing leaves, twigs, etc.

*Yellow ochre, umber*, etc., earthy material, intermixed with clay.

*Brown clay ironstone*, compact, often nodular masses, impure from clay.

**SIMILAR SPECIES.**—Distinguished from other iron-ores, except goethite, by its streak, and from the latter by lack of crystallization.

**REMARKS.**—The occurrences are described, p. 264. The largest deposits which are regularly mined exist in the States of Alabama, Michigan and Tennessee.

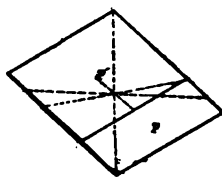
#### SIDERITE. — Spathic Ore.

**COMPOSITION.** —  $\text{FeCO}_3$ , (FeO 62.1,  $\text{CO}_2$  37.9 per cent.) usually with some Ca, Mg or Mn.

**GENERAL DESCRIPTION.** — Occurs in granular masses of a gray or brown color and also in masses with rhombohedral cleavage and in curved rhombohedral crystals, Fig. 336. At times it is quite black from included carbonaceous matter.

**CRYSTALLIZATION.**—Hexagonal. Scalenohedral class, p. 48. Axis  $c = 0.8184$ . Usually rhombohedrons of  $73^\circ$ , often with curved (composite) faces like those of dolomite.

FIG. 336.





**Physical Characters.** H., 3.5 to 4. Sp. gr., 3.83 to 3.88.

LUSTRE, vitreous to pearly. OPAQUE to translucent.

STREAK, white or pale yellow. TENACITY, brittle.

COLOR, gray, yellow, brown or black.

CLEAVAGE, rhombohedron of  $107^\circ$ .

**VARIETIES:**

*Clay Ironstone*, earthy or stony mixtures, with silica, clay, limonite, hematite.

*Blackband*, mixtures with clay and carbon.

*Sphaerosiderite*, secondary siderite in cavities of basalt usually botryoidal.

**BEFORE BLOWPIPE, ETC.**—Decrepitates, becomes black and magnetic and fuses with difficulty. Soluble in warm acids with effervescence. Slowly soluble in cold acids. May react for manganese.

**SIMILAR SPECIES.**—It is heavier than dolomite and becomes magnetic on heating. Some stony varieties resemble varieties of sphalerite.

**REMARKS.**—As described, p. 265, siderite deposits of economic value occur as replacements of limestone and as sedimentary deposits. Stony, impure "clay ironstone" and bituminous "black band" occur as immense strata in England and Wales and this country in Pennsylvania, Ohio, Virginia and Tennessee, always in connection with the Coal Measures. Siderite is common in metallic veins, usually being considered gangue. Sometimes, as at Roxbury, Conn., it has been the ore.

**USES.**—It is used as an ore of iron and when high in manganese it is used for the manufacture of spiegeleisen.

**THE SILICATE IRON ORES\* (Chamosite, Thuringite, Greenalite, Berthierine).**

In various parts of Europe iron ores have been found which are partly silicates. Some have been worked on an extensive scale. In this country the Lake Superior ores are believed to be formed in considerable part by the alteration of such a silicate greenalite.

**COMPOSITION.**—Definite formulæ are difficult, chamosite, thuringite and greenalite are hydrous silicates of iron and aluminum (berthierine is believed to be a mixture of chamosite and magnetite). By averaging analyses the following percentages resulted.

|                 | SiO <sub>2</sub> . | Fe <sub>2</sub> O <sub>3</sub> . | Al <sub>2</sub> O <sub>3</sub> . | FeO.  | MgO. | H <sub>2</sub> O. |
|-----------------|--------------------|----------------------------------|----------------------------------|-------|------|-------------------|
| Greenalite..... | 32.86              | 22.26                            |                                  | 36.40 |      | 8.48              |
| Thuringite..... | 22.8               | 13.5                             | 17.2                             | 36.3  |      | 10.02             |
| Chamosite.....  | 26.04              | 1.3                              | 18.6                             | 39.74 | 2.17 | 12.41             |

\* The "green earths," glauconite, now forming in the marine muds and found in Cretaceous sediments and celadonite are similar in composition.

**GENERAL DESCRIPTION.**—Chamosite is usually oölite or compact, thuringite foliated, greenalite in granules, the colors range from gray through green to black.

**BLOWPIPE CHARACTERS.**—Chamosite is said to fuse easily, thuringite less easily, and both to gelatinize with acids.

**REMARKS.**—A bed 60 ft. thick of chamosite and thuringite at Schmiedefeld, Thuringia, yielded 140,000 tons in 1899. Berthierine at Hayanges, near Metz, is a valuable ore. Other deposits exist in Switzerland, France and Bohemia. Greenalite is abundant in the Mesabi in the ferruginous cherts.

## THE MANGANESE MINERALS.

The minerals described are:

|                  |                      |  |              |
|------------------|----------------------|--|--------------|
| <i>Sulphide</i>  | <i>Alabandite</i>    | MnS  | Isometric    |
| <i>Oxides</i>    | <i>Braunite</i>      | Mn <sub>2</sub> O <sub>3</sub>                             | Tetragonal   |
|                  | <i>Hausmannite</i>   | Mn <sub>2</sub> O <sub>4</sub>                             | "            |
|                  | <i>Pyrolusite</i>    | MnO <sub>2</sub>   |              |
|                  | <i>Polianite</i>     | MnO <sub>2</sub>   | Tetragonal   |
|                  | <i>Psilomelane</i>   | MnO <sub>2</sub> + (H <sub>2</sub> O.K <sub>2</sub> O.BaO) |              |
|                  | <i>Wad</i>           | Mixture of oxides  |              |
| <i>Hydroxide</i> | <i>Manganite</i>     | MnO(OH)  | Orthorhombic |
| <i>Carbonate</i> | <i>Rhodochrosite</i> | MnCO <sub>3</sub>  | Hexagonal    |
| <i>Silicates</i> | <i>Rhodonite</i>     | MnSiO <sub>3</sub>   | Triclinic    |
|                  | <i>Tephroite</i>     | Mn <sub>2</sub> SiO <sub>4</sub>                           | Orthorhombic |

Other silicates containing manganese and elsewhere described are spessartite and piedmontite, and there are mangiferous amphiboles, pyroxenes, axinites and other species.

Manganese is also an important constituent of franklinite, wolframite, huebnerite, and columbite.

## ECONOMIC IMPORTANCE.

The principal economic uses of manganese minerals are in the production of the alloys with iron, *spiegeleisen* and *ferromanganese*, used in the manufacture of steel, and in the making of manganese steels to resist abrasion and shock, such as car wheels, gears, crushing machinery. The method of smelting is very like that used in the manufacture of pig-iron. Manganese is also an important constituent of other alloys, especially manganese bronze and so-called silver bronze.

Minor uses are in the manufacture of chlorine, bromine, oxygen, disinfectants, driers for varnishes; as a decolorizer to remove the iron green color from glass and also, when added in larger quantity, to give an amethystine color to glass and pottery; in the ordinary

dry battery; in calico printing, making green and violet paints, etc.

Certain iron ores are very rich in manganese and are valuable in making spiegeleisen. In 1914,\* 445,827 long tons of manganese iron ores were mined in the United States. Also a large amount of franklinite was used for the production of zinc oxide and 100,198 tons\* of a highly manganese by-product obtained.

In the West, especially in Colorado and Arizona, manganese ores often carry silver, and several thousand tons are smelted each year with other silver-bearing minerals, the manganese acting as a flux. Much of the Arkansas material is also used as flux. In 1914, 39,881 tons were thus used.

The manganese minerals important as ores are the oxides pyrolusite, psilomelane (including wad), braunite and manganite, and sometimes rhodochrosite. In 1914† 2,635 tons were produced mainly in Virginia, Arkansas and Georgia.

Owing chiefly to the fact that "most of the known manganese ore deposits of the United States yield material that must be washed or concentrated to obtain a marketable product"\* this country imports most of its material from Russia, India and Brazil. In 1914 the comparison in long tons was:

|                     | Production. | Imports. |
|---------------------|-------------|----------|
| Manganese Ore.....  | 2,635       | 283,294  |
| Ferromanganese..... | 100,731     | 82,997   |
| Spiegeleisen.....   | 76,625      | 2,870    |

#### THE FORMATION AND OCCURRENCE OF MANGANESE ORES.

##### The Primary Sources.

The igneous rocks contain a small percentage of manganese (Mn 0.77 per cent., Clarke), syenites, porphyries, and basalts are said to contain about 0.36 per cent. (Lindgren).

The schists also contain small percentages of manganese and certain‡ schists carry manganese silicates, *rhodonite* and *tephroite* or one or more of *spessartite* (manganese garnet), *piedmontite* (manganese epidote), or manganese varieties of *pyroxene* or *amphibole*.

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\* *Mineral Resources of the U. S.*, 1914.

† D. F. Hewett in *Mineral Resources of the U. S.*, 1914, Pt. I, p. 166.

‡ See under residual deposits, next page.

The sedimentary rocks contain manganese as oxides or *rhodonite* or *rhodochrosite*.

The ores are secondary and are the result usually of weathering and concentration in some instances combined with contact action. The resulting deposits are chiefly oxides and sometimes carbonates and classify as:

**Contact Deposits**—containing *hausmannite*, *braunite*, *franklinite*, *rhodonite*, *tephroite*, etc., as at Langban and other Wermland deposits of Sweden and at Franklin Furnace, N. J.

**Veins** (lateral secretions) containing *pyrolusite*, *psilomelane*, *manganite*, *polianite*, as at Schwarzenberg, Saxony; Ihlefeld, Harz; and Thuringer Wald; and at Veitsch, Styria; chiefly *rhodochrosite*.

**Replacements**, consisting of *rhodochrosite* or the oxides, limestones by *rhodochrosite*, Las Cabesses, French Pyrenees; porphyry with exception of quartz by *oxides*, Thuringer Wald.

#### **Sedimentary† deposits.**

Consisting of *pyrolusite*, *psilomelane*, *manganite* and earthy mixtures called *wad*.

*As Bog Ores*, usually with *bog iron* and often by aid of organisms. Wickes, Mont.; Hillsborough, New Brunswick; Norway, Sweden.

*As Lake or Sea Beds*. The enormous deposit of Kutais, Trans-Caucasus are oölitic *pyrolusite* cemented by earthy manganese.

**Residual Deposits**, chiefly *pyrolusite*, *psilomelane* and *wad*, sometimes *braunite*. India from decomposing archæan rocks carrying *spessartite* and *rhodonite*. Often with enormous masses of *psilomelane*, *pyrolusite* or *braunite*. Brazil (Minas Geraes) from decomposing schists carrying *rhodonite*, *tephroite* and *spessartite*. Texas from decomposing schists carrying *spessartite*, *piedmontite* and *tephroite*. *Cremora, Va.*—in concentric layers of *pyrolusite* and *psilomelane* forming lumps and larger bodies in clay.

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\* "The lode-like manganese deposits on the north side of the Thuringer Wald exhibit a transformation so complete that only the quartz of the original rock remains unaffected." Beyschlag, Vogt and Krusch, Truscott, 142.

† They are frequently near similar deposits of iron but on account of the relatively easier solubility of the manganese carbonate the deposits usually separate. The manganese oxides are probably precipitated in the colloidal condition, with a tendency to absorb certain oxides especially of barium and potassium but in time crystallize.

**MANGANIFEROUS IRON OR SILVER OR ZINC ORES.**

By far the larger portion of the manganese mined in the United States is in the form of mixtures of iron oxides, with relatively small proportions of manganese oxides, these are obtained chiefly from the Lake Superior region and also from Colorado and Arkansas.

Manganese residues are obtained from the zinc ores of Franklin Furnace, N. J.

Manganiferous silver ores consisting of *psilomelane* and probably other oxides with small quantities of silver and lead minerals are found near the ore bodies at Leadville and elsewhere and used as fluxes, silver being recovered.

**ALABANDITE.—Manganblende.**

COMPOSITION.— $MnS$ , (Mn 63.1, S 36.9 per cent.).

GENERAL DESCRIPTION.—A dark iron-black metallic mineral with an olive green streak. Usually massive, with easy cubic cleavage and occasionally in cubic or other isometric crystals. Also massive granular.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, deep black with brown tarnish. Streak, olive green. H., 3.5 to 4. Sp. gr., 3.95 to 4.04. Brittle.

BEFORE BLOWPIPE, ETC.—Turns brown, evolves sulphur dioxide and fuses. Gives sulphur reactions with soda. Soluble in dilute hydrochloric acid with rapid evolution of hydrogen sulphide.

SIMILAR SPECIES.—It is distinguished from all similar species by its streak.

REMARKS.—The other manganese minerals are derived in part from the alteration of this species. It occurs with other metallic sulphides.

**BRAUNITE.**

COMPOSITION.— $Mn_2O_3$ , but usually containing  $MnSiO_3$ .

GENERAL DESCRIPTION.—Brownish black granular masses and occasional minute tetragonal pyramids almost isometric,  $\epsilon = 0.985$ .

Physical Characters. H., 6 to 6.5. Sp. gr., 4.75 to 4.82.

LUSTRE, submetallic.

OPAQUE.

STREAK, brownish black.

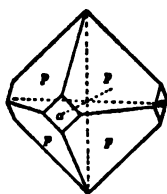
TENACITY, brittle.

COLOR, brownish black to steel gray.

BEFORE BLOWPIPE, ETC.—Infusible. With borax an amethystine bead. Soluble in hydrochloric acid, evolving chlorine and generally leaving gelatinous silica.

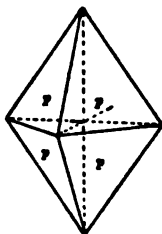
SIMILAR SPECIES.—Resembles hausmannite, but has a darker streak and is harder.

FIG. 337.



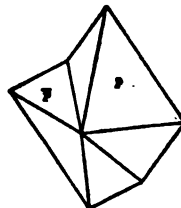
Braunite,  $pp = 70^\circ 7'$ .

FIG. 338.



Hausmannite,  $pp = 74^\circ 34'$ .

FIG. 339.



REMARKS.—As stated on p. 279, it occurs as important ore in the contact deposits of Langban, etc., Sweden, and as large masses in the residual deposits of Vizianagram, India. In the veins at Ilmenau, Thuringia, and Ihlfeld Hartz it occurs crystallized and massive, and it forms part of the Batesville, Arkansas, residual deposit.

#### HAUSMANNITE.

COMPOSITION.— $Mn_2O_4$ . ( $Mn_2O_3$  69.0,  $MnO$  31.0 per cent.).

GENERAL DESCRIPTION.—Black granular strongly coherent masses occasionally in simple and twinned tetragonal pyramids which are more acute than those of braunite,  $c = 1.174$ .

PHYSICAL CHARACTERS.—Opaque. Lustre, submetallic. Color, brownish black. Streak, chestnut brown. H., 5 to 5.5. Sp. gr., 4.72 to 4.85. Strongly coherent.

BEFORE BLOWPIPE, ETC.—Infusible. Colors borax bead amethystine. Soluble in hydrochloric acid with evolution of chlorine.

SIMILAR SPECIES.—Differs from braunite in hardness, streak and absence of silica.

#### PYROLUSITE.—Black Oxide of Manganese.

COMPOSITION.— $MnO_2$ . (Mn 63.2 per cent.).

GENERAL DESCRIPTION.—A soft black mineral of metallic lustre. Frequently composed of short indistinct crystals or radiated needles, but also found compact, massive, stalactitic, and as velvety crusts. Usually soils the fingers. Frequently in alternate layers with psilomelane.

Physical Characters. H., 1 to 2.5. Sp. gr., 4.7 to 4.86.

LUSTRE, metallic or dull.

OPAQUE.

STREAK, black.

TENACITY, rather brittle.

COLOR, black to steel gray.

BEFORE BLOWPIPE, ETC.—Infusible, becomes brown. Usually yields oxygen and a little water in closed tube. Colors borax bead amethystine. Soluble in hydrochloric acid with evolution of chlorine.

**SIMILAR Species.**—Distinguished by its softness and black streak from other manganese minerals.

**REMARKS.**—As described on p. 279, occurs in the vein, replacement, sedimentary and residual deposits and usually associated with psilomelane.

The great sedimentary deposit at Kutais, Transcaucasia, is compact pyrolusite separated by mixed ores and has a thickness of six to sixteen feet. Another enormous deposit exists at Nicopol.

In this country the residual deposits at Crimera, Va., Cartersville, Ga., and Batesville, Ark., and the streaks and pockets in certain hematites of Lake Superior are the important deposits. Other deposits exist in California, Vermont and North Carolina. The purest material for use in glass making is obtained near Sussex, N. B., and from the Tenny Cape district, Nova Scotia.

#### **POLIANITE.**

**COMPOSITION.**— $\text{MnO}_2$  (Mn 63.1 per cent.).

**GENERAL DESCRIPTION.**—A hard, dark gray, submetallic substance occurring in composite groups of minute crystals or as an outer coating on manganite.

**CRYSTALLIZATION.**—Tetragonal  $c = .6646$ . Small crystals on pyrolusite or parallel groupings of pseudorhombic shape.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, submetallic. Color, steel to iron gray. Streak, black. H., 6–6.5. Sp. gr., 4.83–5.02.

**BEFORE BLOWPIPE, ETC.**—Like pyrolusite.

**REMARKS.**—Occurs at Platten, Bohemia, in the typical crystal groups. In other localities is often entirely or partly changed to pyrolusite.

#### **MANGANITE.**

**COMPOSITION.**— $\text{MnO}(\text{OH})$ , (Mn 62.4, O 27.3,  $\text{H}_2\text{O}$  10.3 per cent.).

**GENERAL DESCRIPTION.**—Occurs in long and short prismatic

FIG. 340.



Manganite, Ilfeld, Hartz. N. Y. State Museum.

(orthorhombic) crystals often grouped in bundles with fluted or rounded cross-section and undulating terminal surface, rarely massive, granular or stalactitic.

**Physical Characters.** H., 4. Sp. gr., 4.2 to 4.4.

LUSTRE, submetallic.

OPAQUE.

STREAK, reddish brown to black.

TENACITY, brittle.

COLOR, steel gray to iron black.

BEFORE BLOWPIPE, ETC.—Like pyrolusite, but yields *decided* test for water and very little oxygen.

REMARKS.—Formed in the same deposits as pyrolusite and frequently altered to pyrolusite.

#### PSILOMELANE.—Black Hematite.

COMPOSITION.—Perhaps  $MnO_2 + (H_2O, K_2O \text{ or } BaO) \text{ or } H_4MnO_6$ , with replacement by Ba or K.

GENERAL DESCRIPTION.—A smooth black massive mineral commonly botryoidal, stalactitic or in layers with pyrolusite. Never crystallized.

**Physical Characters.** H., 5 to 6. Sp. gr., 3.7 to 4.7.

LUSTRE, submetallic or dull.

OPAQUE.

STREAK, brownish black.

TENACITY, brittle.

COLOR, iron black to dark gray.

BEFORE BLOWPIPE, ETC.—Infusible. In closed tube yields oxygen and usually water. Soluble in hydrochloric acid, with evolution of chlorine. A drop of sulphuric acid added to the solution will usually produce a white precipitate of barium sulphate.

SIMILAR SPECIES.—Distinguished from pyrolusite by its hardness, and from limonite by its streak.

REMARKS.—Its localities are the same as for pyrolusite, and the two minerals are usually mined together.

#### WAD.—Bog Manganese.

COMPOSITION.—Mixture of manganese oxides, with often oxides of metals other than manganese such as cobalt, copper and lead.

GENERAL DESCRIPTION.—Earthy to compact indefinite mixtures of different metallic oxides, in which those of manganese predominate. Dark brown or black in color; often soft and loose, but sometimes hard and compact.

PHYSICAL CHARACTERS.—Opaque. Lustre dull. Color brown to black. Streak brown. H., 1/2 to 6. Sp. gr., 3 to 4.26. Often soils the fingers.

BEFORE BLOWPIPE, ETC.—As for psilomelane, but often with strong cobalt or copper reactions.



USES.—Wad is used as a paint and in the manufacture of chlorine.

REMARKS.—Large deposits exist at Wickes, Montana; Hillsborough, New Brunswick; and Norway.

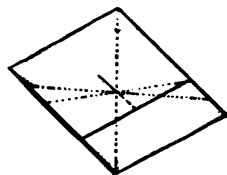
### RHODOCHROSITE.

COMPOSITION. —  $\text{MnCO}_3$ , (MnO 61.7,  $\text{CO}_2$  38.3 per cent.) with partial replacement by Ca, Mg or Fe.

GENERAL DESCRIPTION.—Rose pink to brownish red rhombohedral crystals, usually small and curved like dolomite. Frequently massive cleavable, or granular or compact. Less frequently botryoidal or incrusting.

CRYSTALLIZATION. — Hexagonal. Scalenohedral class, p. 48. Axis  $c = .8184$ . Angles as in siderite. Usual form a rhombohedron of  $73^\circ$ . Optically —.

FIG. 341.



Physical Characters. H., 3.5 to 4.5. Sp. gr., 3.3 to 3.6.

LUSTRE, vitreous to pearly.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, light pink, rose red, brownish red and brown.

CLEAVAGE, parallel to rhombohedron.

BEFORE BLOWPIPE, ETC. — Infusible, but decrepitates violently and becomes dark colored.\* In borax yields amethystine bead. Soluble in warm hydrochloric acid, with effervescence, slowly soluble in the cold acid.

SIMILAR SPECIES. — Distinguished from rhodonite by form, cleavage, effervescence and infusibility.

REMARKS.—The great manganese deposits of Huelva, Spain, are chiefly rhodochrosite, containing rhodonite, and this is being mined in enormous quantities. In the Quelez District, Brazil, rhodochrosite with tephroite forms large lenses which by alteration have yielded psilomelane. Other producing localities are Merionethshire, Wales, and Chevron, Belgium. It is also found in ore-veins, as a gangue mineral in the silver veins of Butte, Montana, Austin, Nev., and elsewhere. It is not mined, in this country.

### RHODONITE.

COMPOSITION. —  $\text{MnSiO}_3$ , with replacement by Fe, Zn or Ca.

GENERAL DESCRIPTION. — Brownish red to bright red, fine

\* May become magnetic from impurities.

grained or cleavable masses and disseminated grains, often coated with a black oxide. Sometimes in triclinic crystals either tabular parallel to  $c$  or like the forms of pyroxene.

CRYSTALLIZATION.—Fig. 342 shows three pinacoids  $a$ ,  $b$  and  $c$ , the hemi-unit prisms  $m$  and  $M$ , and two quarter pyramids  $v$ , and  $v$  of  $a : b : 2c$ . The supplement angles are  $mM = 92^\circ 28'$ ;  $cm = 68^\circ 45'$ ;  $cM = 86^\circ 23'$ .

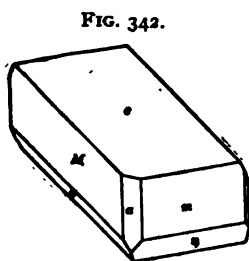


FIG. 342.

Franklin Furnace.

**Physical Characters.** H., 5.5 to 6.5. Sp. Gr., 3.4 to 3.68.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, brownish-red to flesh-red, bright-red, greenish, yellowish.

BEFORE BLOWPIPE, ETC.—Blackens and fuses easily with slight intumescence. With fluxes reacts for manganese and zinc. In powder is partially dissolved by hydrochloric acid, leaving a white residue. If altered may effervesce slightly during solution.

REMARKS.—In the gneisses and crystalline schists rhodonite occurs as a primary alteration product as interbedded layers, lenses and beds often of considerable extent as near Ekaterinenberg, Urals, Langban, Sweden (with iron ore beds) Bukowina, Russia. Near Rosenau, Hungary, the deposit is over forty feet thick. Many other localities exist.

In the United States it occurs at Blue Hill, Maine, Cummington, Mass., Franklin, N. J., in the ore veins of Butte, Montana, and elsewhere.

USES.—Probably to some extent as an ore and a small amount is polished as an ornamental stone. Chiefly important as a source of the oxides.

#### TEPHROITE.

COMPOSITION.— $Mn_2SiO_4$  (MnO.70.2,  $SiO_2$  29.8 per cent.). Usually with some MgO, sometimes with ZnO.

GENERAL DESCRIPTION.—As gray to flesh red masses which cleave (?) in directions at right angles.

CRYSTALLIZATION.—Orthorhombic; crystals rare,  $a : b : c = .4621 : 1 : .5914$ .

PHYSICAL CHARACTERS.—Translucent to transparent. Lustre, vitreous to greasy. Color, ash gray, flesh red, brown. Streak, gray. H., 5.5 to 6. Sp. gr., 4 to 4.1.

BEFORE BLOWPIPE, ETC.—Fusible with some difficulty. Soluble in hydrochloric acid with gelatinous residue.

REMARKS.—Common in certain rocks which by their alteration have yielded manganese deposits as in central Texas and in the Lafayette District, Brazil. First discovered among the Franklin Furnace minerals and later in the Langban and Paisberg, Sweden, deposits in small crystals.

### THE NICKEL AND COBALT MINERALS.

The cobalt minerals described are:

|                      |                  |   |            |
|----------------------|------------------|---|------------|
| <i>Sulphide</i>      | <b>Linnæmite</b> | $(\text{Co.Ni})_2\text{S}_4$                            | Isometric  |
| <i>Sulpharsenide</i> | <b>Cobaltite</b> | $\text{CoAsS}$  | Isometric  |
| <i>Arsenide</i>      | <b>Smaltite</b>  | $(\text{Co.Ni})\text{As}_2$                             | Isometric  |
| <i>Arsenate</i>      | <b>Erythrite</b> | $\text{Co}_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ | Monoclinic |

Cobaltiferous arsenopyrite, pyrite and pyrrhotite occur.

The nickel minerals described are:

|                  |                    |   |            |
|------------------|--------------------|---|------------|
| <i>Sulphides</i> | <b>Millerite</b>   | $\text{NiS}$  | Hexagonal  |
|                  | <b>Pentlandite</b> | $(\text{Fe.Ni})\text{S}$  | Isometric  |
| <i>Arsenide</i>  | <b>Niccolite</b>   | $\text{NiAs}$   | Hexagonal  |
| <i>Arsenate</i>  | <b>Annabergite</b> | $\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$         | Monoclinic |
| <i>Silicates</i> | <b>Garnierite</b>  | $\text{H}_2(\text{Ni.Mg})\text{SiO}_4 \cdot \text{H}_2\text{O}$ |            |

Chloanthite, or highly nickeliferous smaltite; and nickeliferous pyrrhotite and pyrite in which the nickel is supposed to be present as pentlandite are important ores.

#### ECONOMIC IMPORTANCE.

##### Cobalt.

The metal cobalt, has, as yet, no important use; the oxide is used to impart a blue color to glass and pottery. The chief commercial compound is **SMALT**, a cobalt glass, the cobalt replacing the calcium of ordinary glass. This is ground and used as a fine blue pigment, which is unaltered by exposure.

Cobalt blue and Rinmann's green are compounds of cobalt with alumina and zinc oxide respectively.

The extraction of cobalt from a nickeliferous matte is an elaborate chemical operation involving solution in hydrochloric acid, precipitation of manganese and iron as basic carbonates, and of other metals as sulphides, leaving a solution of chloride of nickel and cobalt. From these the cobalt is precipitated with great care, by means of calcium hypochlorite, as cobaltic hydroxide, after which the nickel is precipitated as hydroxide by lime-water. By using selected ores, mattes especially rich in cobalt may be obtained and for ordinary purposes the small nickel contents are neglected.

The amount of available cobalt ore has been greatly increased of late due to the silver-bearing cobalt ores of Cobalt, Ont., but the amount used is small, approximating 20 tons of the oxide each year in this country.

No production of cobalt ores is reported for 1914\* in this country, but Ontario produced 97 tons of ore and New Caledonia exported 920 tons of ore and 25 tons of matte. Germany electrolytically separates cobalt from copper of Belgian Congo.

Metallic nickel is extensively used in different alloys, and, indeed, was first obtained as a residual alloy with copper, iron and arsenic, in the manufacture of smalt. This alloy was called German silver or nickel silver and largely used in plated silverware. Later, a large use for nickel was found in coins, the United States Mint alone using nearly one million pounds between 1857 and 1884. In this alloy copper is in large proportion, the present five cent piece being 25 per cent. nickel, 75 per cent. copper, and in other coins the percentage of copper being still greater. The most extensive application of nickel at present is in the manufacture of nickel steel for armor plates and other purposes. The uses of nickel steel are continually increasing, as the metal has some excellent properties possessed by no other alloy. To a limited extent nickel is used in a nickel-copper alloy for casing rifle bullets. An alloy of iron and nickel containing 30 per cent. of nickel is non-magnetic and is used in electric heaters and in parts of other electrical apparatus.

"Monel metal" an alloy of 68 per cent. nickel, 1.5 per cent. iron and 30.5 per cent. copper made by extracting the nickel and copper from the ore without separating them, is said to be stronger than nickel steel, unaffected by sulphuric acid and silver white in color.

A sulphate of nickel and ammonium is also manufactured in large amounts for use in nickel plating.

The nickel of commerce is nearly all obtained either from the garnierite of New Caledonia or from the deposit of nickel-bearing sulphides of Ontario. The garnierite is smelted in a low blast furnace, with coke and gypsum, and the matte of nickel, iron and sulphur thus produced is alternately roasted and fused with sand, in a reverberatory furnace, until nearly all the iron has been removed. The nickel sulphide, by oxidation, is converted into oxide.

Nickel oxide is obtained from the pyrrhotite and chalcopyrite of Sudbury, Canada. The ore is first roasted to remove much of the sulphur, and is then smelted, together with nickel-bearing slags of previous operations. A nickel matte carrying much

\* *Mineral Industry*, 1914, p. 548.

copper and some iron is produced through which air is blown in a silica-lined Bessemer converter and most of the iron is carried into the slag. A matte, rich in nickel and copper, results. This may be directly roasted and reduced by carbon to produce nickel-copper alloys for the manufacture of German silver. In order to separate the nickel the concentrated matte is fused with sodium sulphate and coke, after which the melted sulphides are allowed to settle. Under these conditions the copper and iron sulphides form a very fluid mass with the soda, and, with some nickel, rise to the top while the lower portions of the mass are highly nickeliferous. The two layers are separated and each is re-treated in much the same manner. The nickel sulphide resulting is partially roasted and is fused with sand, by means of which most of the iron is removed as a silicate in the slag. The nickel sulphide remaining is by oxidation converted into the oxide. The oxide is sold directly to steel makers or may be reduced to metal by mixing with charcoal and heating, white hot, in a graphite crucible.

No nickel ore is reported as produced in this country in 1914. Canada produced\* ore containing 12,937 short tons of nickel in addition to about 200 tons of nickel oxide. New Caledonia exported 94,154 tons of ore and 5,287 tons of matte. Norway and Germany were also producers.

Nickel is now successfully refined by electrolysis, but the details of the process are jealously guarded. It is doubtful, however, if nickel can be separated from cobalt in this manner, although most other impurities are removed.

The Mond process for the extraction of nickel from its ore and for its separation from cobalt promises to become important. The process is based on the discovery that when carbon monoxide is passed over heated nickel, volatile nickel carbonyl,  $\text{Ni}(\text{CO})_4$ , is formed. As cobalt does not react in this way, the separation of nickel from cobalt is easily accomplished. The reconversion of the nickel carbonyl into nickel and carbon monoxide is a simple operation.

#### THE FORMATION AND OCCURRENCE OF COBALT AND NICKEL ORES

Nickel and cobalt occur usually together and are present in

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\* *Mineral Industry*, 1914.

the earth's crust in minute percentages. Nickel less than .01 (Clarke), cobalt between .001 and .0001 (Vogt).

The peridotites and pyroxenic rocks and the serpentines derived from them contain most of these elements.

The occurrences of importance are principally:

### Magmatic Segregations.

(a) Of nickeliferous *pyrrhotite* and *pyrite* and various nickel and cobalt minerals, especially *pentlandite* or *millerite*, as at Sudbury, Ontario; Gap Mine, Pennsylvania; and many small deposits in Norway. (b) Of iron nickel alloys see *Iron*, p. 266.

### Normal Veins.

Containing sulphides and arsenides (*smaltite*, *chloanthite*, *niccolite*, *linnæite*, *cobaltite* and rarer species). In schists and gneiss and conglomerates near basic intrusive dikes and in the dikes themselves, as at the Cobalt, Ontario, district and Annaberg and Schneeberg, Saxony; and Dobschau, Hungary.

**Veins in Serpentine** (Lateral Secretion) containing hydrous silicates or oxides, *garnierite*, *genthite*, *pimelite* or *asbolane*. Due to a weathering of the peridotite to serpentine with a concentration of the nickel or cobalt in the cracks and fissures as in the *garnierite* and *asbolane* deposits of New Caledonia and the *pimelite* of Frankenstein, Silesia.

### LINNÆITE. — Cobalt Pyrites.

**COMPOSITION.** —  $(\text{Co.Ni})_2\text{S}_4$ , often with some Fe or Cu replacing.

**GENERAL DESCRIPTION.** — A steel-gray metallic mineral usually in granular or compact masses intermixed frequently with chalcopyrite; also in small isometric crystals, usually the octahedron *p*, Fig. 343, or this with the cube *a*, Fig. 344.

FIG. 343.

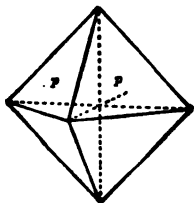
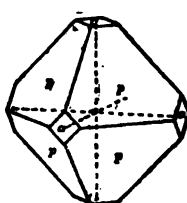


FIG. 344.



**Physical Characters.** H., 5.5. Sp. gr., 4.8 to 5.

LUSTRE, metallic.

OPAQUE.

STREAK, nearly black.

TENACITY, brittle.

COLOR, steel-gray, with reddish-tarnish.

CLEAVAGE, cubic imperfect.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses to a magnetic globule, and gives off fumes of sulphur dioxide. In borax bead gives a deep blue color, and with frequent replacement of borax the red bead of nickel may be obtained. Soluble in nitric acid to a red solution and with separation of sulphur.

**REMARKS.**—Occurs in veins at Müsen and Siegen, Prussia, and Mineral Hill, Maryland. It occurs mostly massive with other cobalt and nickel minerals and with chalcopyrite, pyrrhotite, bornite, at Mine La Motte, Mo., Lovelock's Station, Nev., and in a few other American localities.

**USES.**—Does not occur in large amounts, but is used as a source of both cobalt and nickel.

#### COBALTITE.—Cobalt Glance.

**COMPOSITION.**— $\text{CoAsS}$ , (Co 35.5, As 45.2, S 19.3 per cent.)

**GENERAL DESCRIPTION.**—A silver white to gray metallic mineral resembling linnæite in massive state but in crystals differing in that the forms are the pyritohedron  $\epsilon$ , and cube  $\alpha$ , and these combined, Fig. 347.

**Physical Characters.** H., 5.5. Sp. gr., 6 to 6.1.

LUSTRE, metallic.

OPAQUE.

STREAK, black.

TENACITY, brittle.

COLOR, silver white to gray.

CLEAVAGE, cubic.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses to a magnetic globule and evolves white fumes with garlic odor. Unaltered in closed tube. Soluble in warm nitric acid to rose-red solution, with residue of sulphur and arsenous oxide.

FIG. 345.

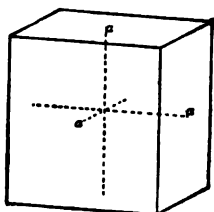


FIG. 346.

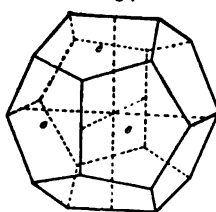
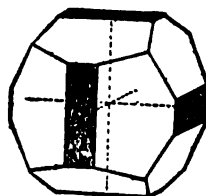


FIG. 347.



**REMARKS.**—Cobaltite occurs in large quantities as an independent stratum 2 feet thick, near Daschkessan, Caucasus, underlying magnetite. At Skutterud, Norway, it occurs free from nickel massive and disseminated in mica schist. In Saxony in veins with barite. At the Cobalt region, Ontario, and in Grant Co., Oregon, in small amounts.

**SMALTITE.—CHLOANTHITE.\***

**COMPOSITION.**— $(\text{Co.Ni})\text{As}_2$ , varying widely in proportion of cobalt and nickel, and usually containing some iron also.

**GENERAL DESCRIPTION.**—A tin-white to steel-gray metallic mineral resembling linnæite and cobaltite. Usually occurs granular massive, but also in isometric crystals, especially modified cubes with curved faces.

**Physical Characters.** H., 5.5 to 6. Sp. gr., 6.4 to 6.6.

LUSTRE, metallic.

OPAQUE.

STREAK, black.

TENACITY, brittle.

COLOR, tin-white to steel-gray.

CLEAVAGE, octahedral.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses, yields white fumes with garlic odor and leaves a magnetic residue, which, when oxidized in contact with frequently replaced borax, yields successively slags colored by iron, cobalt, nickel and possibly by copper. In closed tube yields arsenical mirror. (If sulphur is present also yields a red sublimate.)

Soluble in nitric acid to a red to green solution according to proportion of cobalt and nickel. Partially soluble in hydrochloric acid, especially so after fusion, but yields no voluminous precipitate of yellow arsenic sulphide, as does arsenopyrite when similarly treated.

**SIMILAR SPECIES.**—Differs from linnæite and cobaltite in cleavage, specific gravity and blowpipe reactions. Differs from most arsenopyrite and tetrahedrite in the cobalt blue slags which it yields. It can best be distinguished from cobaltiferous arsenopyrite by the reaction in acids after fusion.

**REMARKS.**—Occurs in veins as stated on p. 289. It was the original mineral deposited in the veins at the Cobalt district, Ontario. It occurs also in veins at Annaberg and Schneeberg, Saxony, Reichelsdorf, Hesse, Gunnison Co., Colorado, and in small amounts at Franklin, N. J., Mine La Motte, Mo., and elsewhere. A ferriferous variety occurs in gneiss at Chatham, Conn.

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\* There is no line between chloanthite  $\text{NiAs}_2$  and smaltite  $\text{CoAs}_2$ , the usual specimen is an isomorphous mixture. The Cobalt district mineral is such a mixture.



**ERYTHRITE.**

**COMPOSITION.**— $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , (CoO 37.5,  $\text{As}_2\text{O}_5$  38.4,  $\text{H}_2\text{O}$  24.1 per cent.).

**GENERAL DESCRIPTION.**—Groups of minute peach red or crimson crystals forming a drusy or velvety surface. Also in small globular forms or radiated or as an earthy incrustation of pink color.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, adamantine or pearly. Color, crimson, peach red, pink and pearl gray. Streak, paler than color. H., 1.5 to 2.5. Sp. gr., 2.91 to 2.95. Flexible in laminæ.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily, evolves white fumes with garlic odor, and leaves a magnetic residue, which imparts the characteristic blue to borax bead. Soluble in hydrochloric acid to a light red solution.

**Asbolane** or asbolite is essentially a mixture of oxides of manganese and cobalt and is grouped under wad, p. 283. The asbolane from the lateral secretion veins in serpentine in New Caledonia has been an important source of cobalt.

**MILLERITE. — Capillary Pyrites.**

**COMPOSITION.**—NiS, (Ni 64.4 per cent.).

**GENERAL DESCRIPTION.**—A brass-colored mineral with metallic lustre, especially characterized by its occurrence in hair-like or needle crystals, often interwoven or in crusts made up of radiating needles.

**Physical Characters.** H., 3 to 3.5. Sp. gr., 5.3 to 5.65.

LUSTRE, metallic.

OPAQUE.

STREAK, greenish-black.

TENACITY, crystals elastic.

COLOR, brass or bronze yellow.

**BEFORE BLOWPIPE, ETC.**—On charcoal spirts and fuses to a brittle magnetic globule, which will color borax red. Soluble in aqua regia to a green solution, yielding with dimethylglyoxime the characteristic crimson precipitate.

**REMARKS.**—Millerite occurs as a magmatic segregation with nickeliferous pyrrhotite at Gap Mines, Pa., as needle crystals in cavities of other minerals such as hematite (Antwerp, N. Y.), dolomite (near St. Louis, Mo.), chalcopyrite (Baden), or in ore veins, especially with iron, cobalt, nickel and bismuth minerals.

**PENTLANDITE.**

**COMPOSITION.**—(Fe.Ni)S. Sudbury average of five analyses Ni 35.57, Co 0.83, Fe 29.06, S 33.25 per cent.

**GENERAL DESCRIPTION.**—Light bronze-yellow, granular masses of metallic lustre. Octahedral cleavage. Color of fresh fracture that of pyrrhotite but tarnishes to more brassy yellow.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 4.6 to 5.

LUSTRE, metallic.

OPAQUE.

STREAK, black.

TENACITY, brittle.

COLOR, light bronze yellow.

NOT MAGNETIC.

**BEFORE BLOWPIPE, ETC.**—Fuses readily to a magnetic globule which gives bead tests for nickel. Soluble in nitric acid, the solution yielding with dimethyl-glyoxime the characteristic crimson precipitate.

**REMARKS.**—Occurs as the important nickel mineral in the nickel-pyrrhotite magmatic segregation at Sudbury, Ontario. It occurs also at Lillehammer, Norway, with chalcopyrite.

### NICCOLITE.—Copper Nickel.

**COMPOSITION.**—NiAs, (Ni 43.9 per cent.). As is replaced to some extent by Sb or S, and Ni by Fe or Co.

**GENERAL DESCRIPTION.**—A massive mineral of metallic lustre, characteristic pale copper red color and smooth impalpable structure. Sometimes the copper-red kernel has a white metallic crust. Occasionally occurs in small indistinct hexagonal crystals.

**Physical Characters.** H., 5 to 5.5. Sp. gr., 7.3 to 7.67.

LUSTRE, metallic.

OPAQUE.

STREAK, brownish-black.

TENACITY, brittle.

COLOR, pale copper red with dark tarnish.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily, giving off white fumes with garlic odor and leaving a magnetic residue, which will color borax bead red and sometimes blue, in which case the borax must be renewed until the cobalt is all removed. In open tube yields a white sublimate and a yellowish-green pulverulent residue. Soluble in concentrated nitric acid to a green solution, which may be tested as under millerite.

**SIMILAR SPECIES.**—Differs from copper in hardness, black streak and brittleness.

**REMARKS.**—Occurs principally in ore veins in the crystalline schists, often with silver ores as in the Saxon mines and many other European localities. Occurs in considerable quantity at la Rioja, Argentina, and Albergera Velha, Portugal. The principal American locality is at Cobalt, Ont. It is also found at Lovelock's, Nevada; Tilt Cove, Newfoundland; Chatham, Conn.; and Thunder Bay, Lake Superior.

**ANNABERGITE.—Nickel Bloom.**

COMPOSITION.— $\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , (NiO 37.4 As<sub>2</sub>O<sub>5</sub> 38.5, H<sub>2</sub>O 24.1 per cent.).

GENERAL DESCRIPTION.—Pale apple-green crusts, and occasionally very small hair-like crystals. Usually occurs on niccolite or smaltite.

PHYSICAL CHARACTERS.—Dull. Color, apple-green. Streak, greenish-white. H., 1.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily to a magnetic button, and becomes dull and yellow during fusion, evolving garlic odor. In closed tube, yields water and darkens. With borax, gives red bead. Soluble in nitric acid.

REMARKS.—Results from the weathering of niccolite or smaltite and is usually found incrusting these minerals though sometimes massive as at Churchill Co., Nevada; and Reichelsdorf, Silesia.

**GARNIERITE.—Noumeite.**

COMPOSITION.— $\text{H}_2(\text{Ni.Mg})\text{SiO}_4 + \text{H}_2\text{O}$ ? very variable.

GENERAL DESCRIPTION.—Loosely compacted masses of brilliant dark-green to pale-green mineral, somewhat unctuous. Structure often small mammelonated, with dark-green, varnish-like surfaces, enclosing dull green to yellowish ochreous material. Easily broken and earthy.

Physical Characters. H., 2 to 3. Sp. gr., 2.27 to 2.8.

LUSTRE, varnish-like, to dull.

OPAQUE.

STREAK, light green to white.

TENACITY, friable.

COLOR, deep green to pale greenish-white.

UNCTUOUS, adheres to the tongue.

BEFORE BLOWPIPE, ETC.—Infusible, decrepitates and becomes magnetic. In closed tube yields water. Borax bead gives nickel reaction. Partially soluble in hydrochloric and nitric acids.

SIMILAR SPECIES.—Differs from malachite and chrysocolla in structure and unctuous feeling. Differs from serpentine in deep color and nickel reaction.

REMARKS.—Occurs as described on p. 289, in lateral secretion veins in serpentine\* in Noumea, New Caledonia, derived from a peridotite. Also from similar weathering of a peridotite at Riddles, Oregon. A similar large deposit is reported in Malaga, Spain.

USES.—Next to the nickel-pyrrhotites it is now the most important source of nickel.

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\* At Locris, near Athens, a dull brown 7 per cent. NiO ore occurs and in eastern Cuba there are vast deposits of limonite carrying 0.8 per cent. of nickel and cobalt, both deposits apparently due to decay of peridotites.

The name GENTHITE has been used for green nickeliferous magnesium silicates of very varying composition which occur coating chromite at Lancaster Co., Pa., and forming a layer in sandstone in Webster Co., N. C., and the name PIMELITE for a similar material with more alumina from Frankenstein, Silesia.

## THE ZINC AND CADMIUM MINERALS.

The zinc minerals described are:

|                                |                     |   |              |
|--------------------------------|---------------------|---|--------------|
| <i>Sulphides</i>               | <b>Sphalerite</b>   | ZnS   | Isometric    |
|                                | <i>Wurtzite</i>     | ZnS   | Hexagonal    |
| <i>Sulphate</i>                | <i>Goslarite</i>    | ZnSO <sub>4</sub> ·7H <sub>2</sub> O                                    | Orthorhombic |
| <i>Oxide</i>                   | <b>Zincite</b>      | ZnO   | Hexagonal    |
| <i>Carbonates</i>              | <b>Smithsonite</b>  | ZnCO <sub>3</sub>   | Hexagonal    |
|                                | <i>Hydrosincite</i> | ZnCO <sub>3</sub> ·2Zn(OH) <sub>2</sub>                                 |              |
|                                | <i>Aurichalcite</i> | (Zn, Cu) <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub> (OH) <sub>2</sub> |              |
| <i>Silicates</i>               | <b>Willemite</b>    | Zn <sub>2</sub> SiO <sub>4</sub>  | Hexagonal    |
|                                | <b>Calamine</b>     | (ZnOH) <sub>2</sub> SiO <sub>3</sub>                                    | Orthorhombic |
| <i>Aluminates and Ferrates</i> | <b>Franklinite</b>  | (Zn, Mn)Fe <sub>2</sub> O <sub>4</sub>                                  | Isometric    |
|                                | <i>Gahnite</i>      | ZnAl <sub>2</sub> O <sub>4</sub>  | Isometric    |

The cadmium mineral described is:

|                 |                    |      |           |
|-----------------|--------------------|------|-----------|
| <i>Sulphide</i> | <i>Greenockite</i> | CdS. | Hexagonal |
|-----------------|--------------------|------|-----------|

## ECONOMIC IMPORTANCE.

The important ores of zinc are sphalerite, smithsonite, and calamine; and, in New Jersey, willemite, zincite and franklinite.

Cadmium is not obtained directly from greenockite but from zinc ores.

In this country, Missouri and New Jersey have for years yielded most of the zinc ore but the development of the "flotation" processes has made new centers of zinc production, such as Montana and Idaho, and the ores of Colorado and Oklahoma have come into the market.\* In all, in 1915, this country produced 492,495 tons of metallic zinc.

More complete statistics for 1914, exclusive of secondary zinc, recovered from old brass and zinc articles, give in short tons:

|                            | Manufactured. | Imported. | Exported. |
|----------------------------|---------------|-----------|-----------|
| Metallic Zinc†.....        | 353,049       | 860       | 64,802    |
| Zinc in Zinc Pigments..... | 70,619        | 2,629‡    | 15,592‡   |
| Zinc Dust.....             | 1,003         | 2,004     | —         |

\* By states in 1914 the yield in tons of contained zinc was in the order:

|                 |         |                |        |
|-----------------|---------|----------------|--------|
| Missouri.....   | 105,994 | Wisconsin..... | 31,113 |
| New Jersey..... | 74,253  | Idaho.....     | 21,106 |
| Montana.....    | 55,790  | Oklahoma.....  | 13,992 |
| Colorado.....   | 48,387  | Kansas.....    | 11,284 |

*Mineral Resources of U. S.*, 1914, Vol. 2, p. 877.

† Of this, 9,631 from foreign ores.      ‡ Oxide.

*Metallic zinc* is obtained by distillation of its roasted ores with carbon. The sulphide and carbonate, by roasting, are converted into oxide, and the silicates are calcined to remove moisture. The impure oxides, or the silicates, are mixed with fine coal and charged in tubes or vessels of clay, closed at one end and connected at the other end with a condenser. These are submitted to a gradually increasing temperature, by which the ore is reduced to metallic zinc, and, being volatile, distills, and is condensed. Apparently successful processes are now in use for the direct deposition of zinc from its ores by electrolysis.

The principal uses of metallic zinc are in galvanizing iron wire or sheets and in manufacturing brass. A smaller amount is made into sheet zinc.

*Zinc oxide*, ground in oil, constitutes the paint zinc white. The oxide may be made from the metal by heating it to a temperature at which the zinc takes fire and drawing the fumes into suitable condensers; or, as in this country, it may be made directly from the ore.

*Other pigments*, also in this country made directly from the ore, are "leaded zinc oxide," and zinc lead oxide, the former having more lead oxide.

"*Lithophone*," an intimate mixture of  $\text{ZnS}$  and  $\text{BaSO}_4$  obtained by chemical precipitation is in this country made chiefly from skimmings and scrap.

The world's production of zinc in metric tons for 1913 was estimated:\*

|                    |         |                    |        |
|--------------------|---------|--------------------|--------|
| United States..... | 323,200 | Great Britain..... | 59,000 |
| Germany.....       | 285,000 | Holland.....       | 24,000 |
| Belgium.....       | 198,000 | Russia.....        | 9,000  |
| France.....        | 70,000  | Norway.....        | 8,000  |

*Zinc Dust* results if the retorts cool rapidly below the freezing point (about  $418^\circ \text{C.}$ ); the vapor condenses as a blue powder containing about ten per cent. of  $\text{ZnO}$ . It is extensively used in the separation of gold from cyanide solutions.

*Cadmium* is obtained almost entirely from the Upper Silesian zinc ores. About  $4\frac{1}{2}$  metric tons were so obtained† in 1914 of which this country imported 1,239 pounds. The first fumes are

\* *Mineral Industry*, 1914, p. 793.

† *Mineral Industry*, 1914, p. 82.

redistilled and finally reduced with carbon. The metal is used in fusible alloys and certain forms of silver plating. The sulphide forms a splendid yellow pigment unaltered by exposure.

#### FORMATION AND OCCURRENCE OF ZINC ORES.

There seems to be no proof of any frequent occurrence of zinc in igneous rocks even in minute quantities. A few analyses indicate its occasional occurrence and Washington states that there are reasons for thinking it is "more apt to be present in acid rocks."

It is reported in traces in the Triassic sediments of Schwarzwald and in sea water.

The occurrences are contact deposits, veins, replacements and residual deposits.

#### Contact Deposits.\*

The celebrated deposit at Franklin Furnace, containing *willemite*, *franklinite*, *zincite*, is probably of this type and the deposits at Tres Hermanas, New Mexico, chiefly *willemite* and the Magdalena Mines, New Mexico containing much sphalerite, are in contact zones.

#### Veins.

Sphalerite is one of the common sulphides of the mineral veins.

#### Replacements in Sedimentary Rocks.

The most important zinc deposits of the world occur in limestone, usually with lead, and possibly concentrated there by circulating waters bearing sulphate solutions from which the zinc was precipitated principally as the sulphide, which later formed carbonate, *smithsonite* or silicate *calamine*. The latter are usually above the sulphides. At Moersnet the oxidized ores extend from the surface to a depth of 200 to 300 feet, the sulphides underlying. Similar great deposits exist in Silesia; Bleiberg, Carinthia; and the Mississippi Valley, especially near Joplin, Mo.

Metasomatic replacement is claimed specifically† for Bleiberg, Carinthia, Upper Silesia, part of Moersnet‡ and some others. The origin of the zinc solutions is disputed.

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\* Lindgren, "Mineral Deposits," 675 and 694.

† Beyerslag, Vogt and Krusch, Truscott's translation, 42 and 183.

‡ Lindgren, "Mineral Deposits," 416.

**Residual Deposits of *smithsonite* and *calamine* as at the Bertha Mines, Va.**

**SPHALERITE. — Blende, Zinc Blende, Black-Jack.**

**COMPOSITION.** —  $\text{ZnS}$  (Zn, 67 per cent.). Often contains Cd, Mn, Fe.

**GENERAL DESCRIPTION.** — A mineral of resinous lustre shading in color from yellow through brown to nearly black and transparent to translucent. It occurs frequently cleavable massive but also in crystals and in compact fine-grained masses or alternate concentric layers with galenite.

FIG. 348.

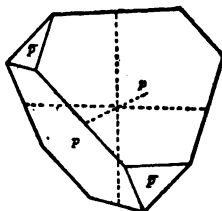


FIG. 349.

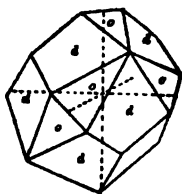
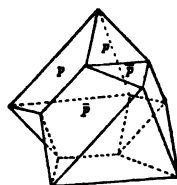


FIG. 350.



**CRYSTALLIZATION.** — Isometric. Hextetrahedral class, p. 62. Usually the dodecahedron  $d$  with the tetrahedron  $p$  and a modifying tristetrahedron  $o = (a : 3a : 3a)$ ;  $\{311\}$ . Fig. 349, usually with rounded faces. More rarely the  $+$  and  $-$  tetrahedron, Fig. 348 and sometimes in twin crystals like Fig. 350.

Index of refraction for yellow light, 2.3692.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 3.9 to 4.1.

LUSTRE, resinous.

TRANSPARENT to translucent.

STREAK, white to pale brown.

TENACITY, brittle.

COLOR, yellow, brown, black; rarely red, green or white.

CLEAVAGE, parallel to rhombic dodecahedron (angles  $120^\circ$  and  $90^\circ$ ).

**BEFORE BLOWPIPE, ETC.** — On charcoal fuses with difficulty, but readily yields a sublimate, sometimes brown at first from cadmium and later yellow while hot, white when cold and becoming bright green if moistened and ignited with cobalt solution. With soda gives a sulphur reaction. Soluble in hydrochloric acid with effervescence of hydrogen sulphide.

**SIMILAR SPECIES.** — Smaller crystals sometimes slightly resemble garnet or cassiterite, but are not so hard.

REMARKS.—The occurrences are as stated on p. 297. It is obtained largely as concentrates in southwest Missouri, Wallace, Idaho; Kansas, Miami, Oklahoma, at Friedensville, Pa., in the southwestern part of Wisconsin, at Pulaski, Va., and at many other places. In small quantities it is of very common occurrence.

WURTZITE.— $\text{ZnS}$ , found in small hexagonal crystals at Joplin, Mo. (prism and base), and Butte, Mont. (pyramidal). Also occurs in concentric layers of radiating fibers (Schalenblende) with sphalerite at Pribram, Bohemia; Pontpeau, France; Liskeard, Cornwall. The Schalenblende of Geroldseck, Baden, is all wurtzite. In physical and blowpipe tests essentially like sphalerite.

GOSLARITE.—Zinc Vitriol.  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , is formed by the oxidation of sphalerite in damp locations. It is a white or yellowish earthy mineral with nauseous astringent taste. Usually an incrustation or mass shaped like the original sphalerite or in stalactites. Rarely needle-like orthorhombic crystals. Goslarite is formed by the oxidation of sphalerite, especially in the presence of iron sulphides. Its interesting feature is that many great zinc deposits appear to have been precipitated from sulphate solutions.

### ZINCITE.—Red Zinc Ore.

COMPOSITION.— $\text{ZnO}$ , (Zn 80.3 per cent.) with usually some Mn or Fe.

GENERAL DESCRIPTION.—A deep red to brick-red adamantine mineral occurring in lamellar or granular masses, either in calcite or interspersed with grains and crystals of black franklinite and yellow to green willemite. A few hexagonal pyramids have been found.

Physical Characters. H., 4 to 4.5. Sp. gr., 5.4 to 5.7.

LUSTRE, sub-adamantine. TRANSLUCENT.

STREAK, orange yellow. TENACITY, brittle.

COLOR, deep red to orange red.

CLEAVAGE, basal and prismatic yielding hexagonal plates.

BEFORE BLOWPIPE, ETC.—Infusible. On charcoal gives reactions for zinc as described under sphalerite. In closed tube blackens, but is again red on cooling. With borax usually gives amethystine bead. Soluble in hydrochloric acid without effervescence.

SIMILAR SPECIES.—Differs from realgar and cinnabar in its associates, infusibility and slow volatilization.

REMARKS.—Occurs at Sterling Hill, near Ogdensburg, and Mine Hill, near Franklin Furnace, N. J., constituting only about one half per cent. of the average ore. Also in small amounts in Schneeberg, Saxony; the lead mines of Tuscany; Olkusz, Poland, and elsewhere.

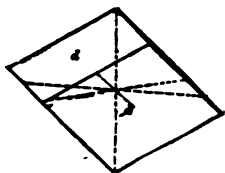


**SMITHSONITE. — Dry Bone, Calamine.**

**COMPOSITION.** —  $\text{ZnCO}_3$  ( $\text{ZnO}$ , 64.8;  $\text{CO}_2$ , 35.2 per cent.).

**GENERAL DESCRIPTION.** — Essentially a white vitreous mineral but often colored yellowish or brownish by iron. Structure stalactitic or botryoidal, or with drusy crystal surface; also in porous cavernous masses and granular. Sometimes of decided colors, as deep green or bright yellow, from copper or cadmium respectively.

FIG. 351.



**CRYSTALLIZATION.** — Hexagonal. Scalenohedral class, p. 48. Axis  $c = 0.8063$ . Usually

small rhombohedrons of  $73^\circ$ , Fig. 351, like those of siderite.

Optically —.

**Physical Characters.** H., 5. Sp. gr., 4.3 to 4.5.

LUSTRE, vitreous to dull.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, shades of white, more rarely yellow, green, blue, etc.

CLEAVAGE, parallel to rhombohedron ( $107^\circ$ ).

**BEFORE BLOWPIPE, ETC.** — Infusible but readily yields white sublimate on coal, often preceded by brown of cadmium. The sublimate becomes yellow when heated and becomes bright green when moistened with cobalt solution and then heated. Soluble in acids with effervescence.

**SIMILAR SPECIES.** — Distinguished from calamine by its effervescence and from other carbonates by its hardness.

**REMARKS.** — Occurs secondary after sphalerite as a replacement of limestone or dolomite, and as residual material. The many zinc deposits usually consist in their upper portions of smithsonite and calamine; this is the case at Moresnet, Silesia, many of the deposits of the Mississippi Valley, and the Magdalena District, New Mexico.

**HYDROZINCITE. — Zinc Bloom.**

**COMPOSITION.** —  $\text{ZnCO}_3 \cdot 2\text{Zn(OH)}_2$  ( $\text{ZnO}$  75.3,  $\text{CO}_2$  13.6,  $\text{H}_2\text{O}$  11.1 per cent.).

**GENERAL DESCRIPTION.** — Usually a soft white incrustation upon other zinc minerals, or as dazzling white stalactites, or earthy and chalk like.

**PHYSICAL CHARACTERS.** — Opaque. Lustre, dull or pearly. Color, pure white to yellowish. Streak shining white. H., 2 to 2.5. Sp. gr., 3.58 to 3.8.

**BEFORE BLOWPIPE, ETC.** — Infusible. Coats the coal like smithsonite. Yields water in closed tube. Soluble in cold dilute acids with effervescence.

**REMARKS.** — Hydrozincite results from the alteration of other zinc ores and occurs in minor quantities in many zinc deposits. Larger quantities have been found at Santander, Spain; Raibl, Carinthia and Constantine, Algeria.

**AURICHALCITE**,  $(\text{Zn}, \text{Cu})_2(\text{CO})_2(\text{OH})_2$ , in pale bluish green and often velvety incrustations often on smithsonite. Sometimes pearly imperfect crystals.  $H = 2$ , Sp. gr., 3.54 to 3.64.

**BEFORE BLOWPIPE, ETC.**—Infusible, colors flame green and yields white coating made green by moistening with cobalt solution and igniting. Soluble in acids with effervescence.

**REMARKS.**—Occurs in Zacatecas, Mexico; Salt Lake Co., Utah; Santa Caterina, Arizona; Laurium, Greece; Rezbanya, Hungary; and many other localities.

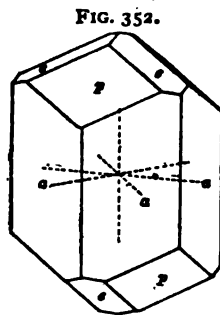
### WILLEMITE.—Troostite.

**COMPOSITION.**— $\text{Zn}_2\text{SiO}_4$ , ( $\text{ZnO}$ , 72.9;  $\text{SiO}_2$ , 27.1); often with much manganese replacing zinc.

**GENERAL DESCRIPTION.**—Compact, translucent, somewhat resinous material, yellow or greenish or brownish red in color, often mottled; granular mixtures with black franklinite; transparent and opaque prismatic crystals often large (Franklin, N. J.), Fig. 352.

Brown, granular masses with minute crystals (Altenberg, Belgium).

Dark gray cellular masses with radial aggregates of slender crystals (Tres Hermanas, New Mexico).



**CRYSTALLIZATION.**—Hexagonal. Class of third order rhombohedron, p. 54. Axis  $c = 0.6775$ .  $p = \{10\bar{1}1\}$ ,  $e = \{01\bar{1}2\}$ ,  $a = \{11\bar{2}0\}$ . Supplement angles are  $pp = 64^\circ 30'$ ;  $ee = 36^\circ 47'$ .

**Physical Characters.**  $H., 5$ . Sp. gr. 3.89 to 4.2.

LUSTRE, resinous.

TRANSPARENT to opaque.

STREAK, nearly white.

TENACITY, brittle.

COLOR, greenish to sulphur yellow, apple green, white, flesh red, gray, brown and blue. *BB.*

**REMARKS.**—Occurs as the result of contact metamorphism (presumably of calamine) in its two most important localities, Sussex County, New Jersey, and Tres Hermanas, New Mexico. Also found in Altenberg near Moresnet in a layer with calamine and smithsonite; and in Stolberg in veins. From Greenland blue colored crystals are reported, and it has been recognized at Socorro, New Mexico, and Clifton, Arizona.

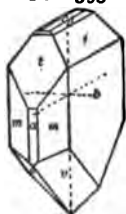
*Similar species*

### CALAMINE.—Electric Calamine.

**COMPOSITION.**— $(\text{ZnOH})_2\text{SiO}_3$ , ( $\text{ZnO}$ , 67.5;  $\text{SiO}_2$ , 25.0;  $\text{H}_2\text{O}$ , 7.5 per cent.).

**GENERAL DESCRIPTION**—A white or brownish white vitreous mineral frequently with a drusy surface or in radiated groups of crystals, the free ends of which form a ridge or cockscomb, also, but more rarely, small distinct transparent crystals. It occurs also granular, stalactitic, botryoidal and as a constituent of some clays.

FIG. 353.



Altenberg.

**CRYSTALLIZATION**.—Orthorhombic. Hemimorphic class, p. 41. Axes  $a : b : c = 0.783 : 1 : 0.478$ . The crystals are usually tabular, the broad face being the brachypinacoid  $b$ , while the prism  $m$  is relatively small.  $v$  is the pyramid  $2a : b : 2c; \{121\}$ .

Optically +, with acute bisectrix vertical.  $2E$  for yellow light  $= 78^\circ 39'$ .

**Physical Characters.** H., 4.5 to 5. Sp. gr., 3.4 to 3.5.

LUSTRE, vitreous to pearly.

OPAQUE to transparent.

STREAK, white.

TENACITY, brittle.

COLOR, yellow to brown, white, colorless, rarely blue or green.

**BEFORE BLOWPIPE, ETC.**—Fusible only in finest splinters. With soda and borax, on charcoal yields a white coating, which is made bright green by heating with cobalt solution. In closed tube, yields water. With acids, dissolves, leaving a gelatinous residue.

**SIMILAR SPECIES.**—It is softer than prehnite, harder than cerussite, and gelatinizes with acids. It differs from willemite in water reaction, and from stilbite in difficulty of fusion.

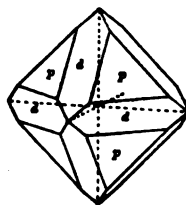
**REMARKS.**—Occurs usually with smithsonite in upper portions of the great zinc replacement deposits, p. 297, or as residual material. Sometimes forms separate deposits as at Herbesthal, Belgium, or may be with hydrozincite as at Cumillas Santander, Spain. In this country it has been mined at Granby, Mo., Sterling Hill, N. J., Bertha, Va., and various localities in Tennessee, Arkansas and Nevada.

### FRANKLINITE.

**COMPOSITION.**— $(\text{Fe.Mn.Zn})(\text{Fe.Mn})_2\text{O}_4$ .

**GENERAL DESCRIPTION.**—A black mineral resembling magnetite. Occurs in compact masses, rounded grains and octahedral crystals. Only slightly magnetic and generally with brown streak. The red zincite and yellow to green willemite are frequent associates. The crystals are modified octahedrons rarely sharp cut as in magnetite.

FIG. 354.



**Physical Characters.**—H., 6 to 6.5. Sp. Gr., 5 to 5.2.

LUSTRE, metallic or dull.

OPAQUE.

STREAK, brown to black.

TENACITY, brittle.

COLOR, black.

Breaks parallel to octahedron.

Slightly magnetic at times.

**BEFORE BLOWPIPE, ETC.**—Infusible. On charcoal with soda gives white coat of zinc oxide. In beads gives manganese reaction. Slowly soluble in hydrochloric acid with evolution of some chlorine.

**SIMILAR SPECIES.**—Distinguished from magnetite and chromite by bead tests and associates.

**REMARKS.**—The only noteworthy locality is that in the vicinity of Franklin Furnace, New Jersey. Here, however, the deposit is large and has been extensively developed.

**USES.**—The zinc is recovered as zinc white and the residue is smelted for spiegeleisen an alloy of iron and manganese used in steel manufacture. Franklinite has also been ground for a dark paint.

**GAHNITE.**—Zinc Spinel,  $ZnAl_2O_4$ . Octahedral crystals of green to black color. Usually opaque and vitreous and with gray streak. H., 7.5 to 8. Sp. gr., 4 to 4.6. On charcoal infusible but gives the coating of zinc oxide. Occurs in talcose schist at Falun, Sweden, in greenish crystals in Calabria, etc., and in this country especially with franklinite and willemite at Franklin Furnace, N. J., and with pyrite at Rowe, Mass.

#### GREENOCKITE.

**COMPOSITION.**—CdS, (Cd, 77.7 per cent.)

**GENERAL DESCRIPTION.**—Usually a bright yellow powder upon sphalerite, or a yellow coloration in smithsonite. Very rarely as small hemimorphic hexagonal crystals,  $d = 0.8111$ .

**PHYSICAL CHARACTERS.**—Translucent. Lustre earthy or adamantine. Color yellow to orange yellow or bronze yellow. Streak orange yellow. H., 3 to 3.5. Sp. gr., 4.9 to 5.0.

**BEFORE BLOWPIPE, ETC.**—Infusible, but is easily volatilized in the reducing flame, coating the coal with a characteristic brown coat and a iridescent tarnish. In closed tube, turns carmine red on heating, but is yellow on cooling. Soluble in strong hydrochloric acid, with effervescence of hydrogen sulphide.

**REMARKS.**—Occurs as crystals in igneous rocks with prehnite at Bishopstoun, Scotland. In many localities it occurs incrusting sphalerite\* as at Friedensville, Pa., and in Missouri. In Marion County, Arkansas, it colors smithsonite, forming the so-called "turkey fat" ore.

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\* In deposits of wurtzite and sphalerite (Schalenblende) the greenockite is principally in the wurtzite. One analysis (Pribram) showing 3.66 per cent.

### THE TIN MINERALS.

The minerals described are:

|                 |                    |                  |            |
|-----------------|--------------------|------------------|------------|
| <i>Sulphide</i> | <i>Stannite</i>    | (Cu.Sn.Fe)S      | Isometric  |
| <i>Oxide</i>    | <i>Cassiterite</i> | SnO <sub>2</sub> | Tetragonal |

Staniferous pyrite occurs in the Bolivian mines and tin is also found as an occasional constituent of tantalite, columbite, and other columbates and tantalates.

It is also an essential constituent of a few rare species.\*

#### ECONOMIC IMPORTANCE.

*Cassiterite* is the only ore of tin, and while deposits exist in this country (in Virginia, North and South Carolina, Dakota, Alaska and elsewhere, the product for 1914 was only ore from Alaska, equivalent to 104 tons of metallic tin).† The world's supply of tin, amounting yearly to about 125,000 long tons, comes chiefly from the East India islands and Bolivia.

The following figures are given for 1915:‡

|  | Long Tons.    |
|--|---------------|
| Straits and Malay Peninsula (exports)..... | 66,760        |
| Banka and Billiton (sales).....            | 15,093        |
| Bolivia (exports).....                     | 18,800        |
| China (exports and production).....        | 7,097         |
| Cornwall (production).....                 | 4,000         |
| Australia (exports).....                   | 2,275         |
| South Africa (production).....             | 2,158         |
| Nigeria.....                               | 1,899         |
|  | <hr/> 118,082 |

The principal use of tin is for the manufacture of tin plate—sheet-iron coated with tin—which is used for making cans, household utensils, etc. Tin is also largely used in alloys, such as bronze, bell metal, pewter, solder and tin amalgam. Tinfoil is also made from it. Large quantities of sodium stannate are used in calico printing.

The ore as mined is first separated from gangue and impurities by washing, jigging, etc., and if necessary, is then calcined or roasted, to remove volatile elements, such as sulphur, arsenic, antimony.

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\* Such as canfieldite, franckeite, kyllindrite, nordenskiöldine.

† *Mineral Production U. S.*, 1914, Summary by H. D. McCaskey.

‡ *Engineering and Mining Journal*, 1916, p. 67.

The concentrated and purified ore may then be smelted with carbon in a shaft furnace. The modern practice is, however, to smelt the ore for several hours in a reverberatory furnace with coal. The liquid tin is drawn off and the slags are resmelted at a higher temperature, frequently requiring the addition of iron or of lime to aid in the separation of the tin, which they still contain. The impure metal obtained is slowly heated to a temperature but little above the melting point of tin; comparatively pure tin separates and this is further purified by oxidation. This oxidation is accomplished either by forcing green wood under the liquid metal causing violent agitation or by repeatedly pouring the melted tin in a thin stream from ladles. Tin may also be refined by electrolysis.

#### FORMATION AND OCCURRENCE OF TIN DEPOSITS.

Tin oxide occurs in granite\* in amounts rarely exceeding 0.05 per cent. and occasionally minute crystals of cassiterite are visible.

In granite pegmatites, cassiterite is sometimes more abundant as in the Black Hills, South Dakota. In Durango and Jalisco, Mexico, it occurs in a rhyolitic surface flow.†

The primary source of tin therefore is an acid magma and all important deposits are derived from such magmas by pneumatolytic action,\* p. 242, in which two great stages are recognized.

First, extraction from the acid magma by aid of fluorine and its compounds, the tin in gaseous state exhaling through cracks in the crust from the still molten interior of the magma.

*Second.* The deposition in the fissures and in the country rock and the conversion of the latter into "grëisen"§ by the introduction of tin, fluorine, lithium and silica.

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\* Especially in the mica, but also in the feldspar.

† Lindgren "Mineral Deposits," p. 632.

‡ "One entire class of deposit, that of the tin lodes, owes its existence entirely to the action of these gases and vapors either between themselves or upon the rocks with which they come in contact." Beyschlag, Vogt and Krusch, "Ore Deposits," p. 174.

§ Coarse-grained rocks consisting of quartz, mica, topaz, or tourmaline and cassiterite. For the Erzgebirge, Lindgren quotes: Quartz 50.28, topaz 12.14, lithia, mica, 36.80, cassiterite 0.43, "Mineral Deposits," p. 620.

**Tin Veins.**

The great deposits are veins or lodes in or near granite such as the long-worked deposits of the Saxon and Bohemian Erzgebirge and of Cornwall and Devon, England.

The great deposits of Mt. Bischof, Tasmania, are in "intensely altered"\* porphyritic dikes but derived from the same magma as a distant granite mass.

The veins worked in the "straits" are in limestone but surrounded by granite hills.

The Bolivian veins at Oruro contain silver minerals and much pyrite, but the pneumatolytic action is indicated by the abundant tourmaline in the country rock.

**Contact Deposits.**

The contact deposits at Pitkaranta, Finland, include not only copper and iron ores but cassiterite with microscopic topaz and with scheelite and fluorite.

**Residual Deposits.**

The erosion and weathering of tin deposits results in the formation of placers or "gravels," some just below the outcrop as at Mt. Bischoff, Tasmania, but usually further from the parent rock.

The weathering removes sulphides and the gravels yield the purest tin. About three quarters of the world's supply comes from such deposits, chiefly Malay Peninsula, Banka and Billiton, but also China, Siam, New South Wales and Alaska.

**STANNITE.—Tin Pyrites.**

**COMPOSITION.**—(Cu,Sn,Fe)S. Uncertain.

**GENERAL DESCRIPTION.**—A massive, granular mineral, of metallic lustre and steel-gray color. It is often intermixed with the yellow chalcopyrite.

**PHYSICAL CHARACTERS.**—Opaque. Lustre metallic. Color steel gray to nearly black. Streak black.  $H = 4$ . Sp gr., 4.5 to 4.52 Brittle.

**BEFORE BLOWPIPE, ETC.**—In the reducing flame fuses. In the oxidizing flame yields  $SO_2$ , and is covered by white oxide, which becomes bluish-green when heated with cobalt solution. Soluble in nitric acid to a green solution, with separation of sulphur and oxide of tin. With soda, gives sulphur reaction.

**REMARKS.**—Stannite occurs in comparatively small amount in the tin regions of Cornwall, Zinnwald and Bolivia. In this country it has been found at the Peerless Mine, Black Hills, South Dakota.

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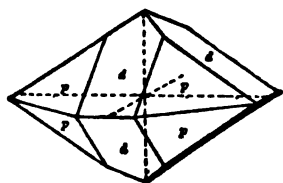
\* Roughly 35 per cent. topaz, 65 per cent. quartz, Beyschlag, Vogt and Krusch, p. 445

**CASSITERITE.—Stream Tin. Tin Stone.**

**COMPOSITION.**— $\text{SnO}_2$ , (Sn 78.6 per cent.), and usually with some  $\text{Fe}_2\text{O}_3$ , and sometimes  $\text{Ta}_2\text{O}_5$ ,  $\text{As}_2\text{O}_5$ ,  $\text{SiO}_2$ , or  $\text{Mn}_2\text{O}_3$ .

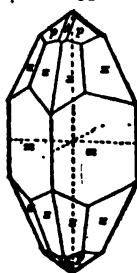
**GENERAL DESCRIPTION.**—A hard and heavy brown to black mineral occurring either in brilliant adamantine crystals or more frequently in dull botryoidal and kidney-shaped masses and rounded pebbles, often with a concentric or fibrous radiated structure.

FIG. 355.



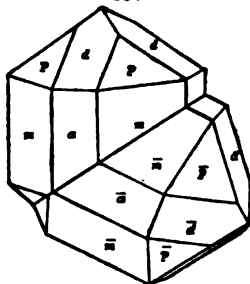
Stoneham, Me.

FIG. 356.



Cornwall, Eng.

FIG. 357.



Zinnwald.

**CRYSTALLIZATION.**—Tetragonal. Axis  $c = 0.672$ . Common forms are the unit first and second order pyramids and prisms  $p$ ,  $a$ ,  $m$ , and  $d$ , and the ditetragonal pyramid  $s = (a : \frac{3}{2}a : 3c)$ ;  $\{321\}$ . Supplement angles  $pp = 58^\circ 19'$ ;  $dd = 46^\circ 28'$ ;  $ms = 24^\circ 59'$ .

Frequently twinned parallel to the second order pyramid, Fig. 357.

Optically + with high indices of refraction 1.996 and 2.093.

**Physical Characters.** H., 6 to 7. Sp. gr., 6.8 to 7.1.

LUSTRE, adamantine to dull. OPAQUE to translucent.

STREAK, white or pale brown. TENACITY, brittle.

COLOR, brown to nearly black, sometimes red, gray, or yellow.

CLEAVAGES, indistinct pyramidal and prismatic.

**BEFORE BLOWPIPE, ETC.**—Infusible, but in powder becomes yellow and luminous. On charcoal with soda and strong heat yields white sublimate which is made bluish green by heating with cobalt solution. Insoluble in acids.

The uncrushed mineral placed on a piece of zinc in dilute hydrochloric acid is coated with gray metallic tin.

**VARIETIES.**

*Tin Stone.*—Crystals and granular masses.



**Wood Tin.**—Masses with concentric structure, the zones being of different color and internally fibrous.

**Stream Tin.**—Rounded pebbles and grains found in alluvial deposits.

**SIMILAR SPECIES.**—The high specific gravity distinguishes it from silicates which it resembles, and the infusibility and insolubility distinguish it from wolframite, etc.

**REMARKS.**—In America the chief localities are Alaska; Harney Peak, South Dakota; Temescal, California; Gaffney, South Carolina; and Lincolnton, North Carolina; Shenandoah Valley, Virginia; and Durango, Mexico. It has been found also in New Hampshire, Maine, Massachusetts, Alabama, Wyoming and Montana.

### THE TITANIUM MINERALS.

The minerals described are:

|               |                    |                  |              |
|---------------|--------------------|------------------|--------------|
| <i>Oxides</i> | <i>Rutile</i>      | TiO <sub>2</sub> | Tetragonal   |
|               | <i>Octahedrite</i> | TiO <sub>2</sub> | "            |
|               | <i>Brookite</i>    | TiO <sub>2</sub> | Orthorhombic |

Titanium is also a constituent of *ilmenite* and *titanite*, and occurs in certain varieties of common silicates, *pyroxene*, *amphibole*, *mica*, *garnet* (schorlomite), *chrysolite* as well as in a number of titanites and titanosilicates.

### ECONOMIC IMPORTANCE.

Although the ninth in quantity of the elements in the earth's crust, titanium has few uses. The production for 1914 at the Roseland, Va., mines was equivalent to 138 tons of titanic oxide.\* Oxide of titanium is used to impart a pinkish color to artificial teeth and an ivory-like appearance to porcelain and from it titanium carbide electrodes for arc lights are made. Ferrotitanium alloy is assuming importance as a deoxidizer in casting steel ingots for rolling mills. Also used for incandescent lamp filaments, coloring material for ceramics and various salts used in dyeing.

### FORMATION AND OCCURRENCE OF DEPOSITS.

#### Titanium Deposits.

The earth's crust contains 0.43 (Clarke) per cent. of titanium, much of which is in the magmatic segregation of ilmenite and titaniferous magnetite already mentioned, p. 263.

*Rutile* in economic quantities is also the result of magmatic segregation and four important localities exist:

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\* *Mineral Resources of the U. S.*, 1914.

In Amherst and Nelson counties, Va., in syenite, grading into gabbro and with gabbro dikes.

At Kragerö, Norway, "streak-like" in granite with dikes on both sides.

At St. Urbain's Bay, St. Paul, Canada, where the ilmenite segregations run high (up to 20 per cent.) in orange red rutile.

At Mt. Crawford, So. Australia, where rutile crystals in economic quantity can be washed from a kaolinized dike.

### RUTILE.—Nigrine.

COMPOSITION.— $\text{TiO}_2$ , (Ti 61 per cent.).

GENERAL DESCRIPTION.—Brownish red to nearly black prismatic crystals often included in other minerals in hair-like or needle-like penetrations. Also coarse crystals embedded in quartz, feldspar, etc., or in parallel and crossed and netted needles upon hematite or magnetite. Occasionally massive when black and iron bearing.

FIG. 358.

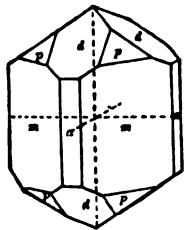
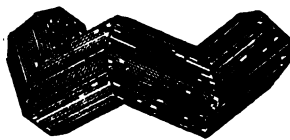


FIG. 359.



FIG. 360.



Magnet Cove, Ark.

CRYSTALLIZATION.—Tetragonal. Axis  $c = 0.644$ . Very close to cassiterite in angles and forms. Usual combinations are unit first and second order pyramids,  $p$  and  $d$ , and first and second order prisms,  $m$  and  $a$ . Often twinned in knees, Fig. 360, and rosettes, Fig. 359. As fine hair-like inclusions, Fig. 216. Prisms often striated vertically.

Supplement angles  $pp = 56^\circ 52'$ ;  $dd = 45^\circ 2'$ .

Optically + with very high indices of refraction 2.616 and 2.902 for yellow light.

**Physical Characters.** H., 6 to 6.5, Sp. gr., 4.15 to 4.25.

LUSTRE, adamantine to nearly metallic. OPAQUE to transparent.

STREAK, white, pale brown.

TENACITY, brittle.

COLOR, reddish brown, red, black, deep red when transparent.

BEFORE BLOWPIPE, ETC.—Infusible. In salt of phosphorus dissolves *very* slowly in the oxidizing flame to a yellow bead which becomes violet in the reducing flame. Insoluble in acids.

SIMILAR SPECIES.—It is redder and of lower specific gravity than cassiterite. The nearly metallic lustre, weight and infusibility separate it from garnet, tourmaline, vesuvianite, and pyroxene.

REMARKS.—In addition to the magmatic segregations mentioned rutile occurs as an accessory mineral in the igneous rocks, in the sediments, with the hardening shales and the bauxite deposits and in the metamorphic rocks. It is often included in quartz and feldspar.

In this country notable localities are Graves Mt., Ga., Magnet Cove, Ark., and Alexander Co., N. C.

OCTAHEDRITE.— $\text{TiO}_2$ . In small pyramidal tetragonal crystals  $\dot{c} = 1.777$ . Either black opaque and nearly metallic, or brown translucent and adamantine.

BROOKITE =  $\text{TiO}_2$ . Orthorhombic. Axes  $\delta : \bar{\delta} : \dot{c} = 0.842 : 1 : 0.944$ .

Either brown translucent crystals which are thin and tabular, or black opaque crystals of varied habit.

## ZIRCONIUM, THORIUM, CERIUM, YTTRIUM MINERALS.

The minerals described are:

|                   |                        |  |              |
|-------------------|------------------------|--|--------------|
| <i>Oxide</i>      | <i>Zirconium oxide</i> | $\text{ZrO}_2$                                     |              |
| <i>Phosphates</i> | <b>Monazite</b>        | $(\text{Ce, La, Di})\text{PO}_4$                   | Monoclinic   |
|                   | <i>Xenotime</i>        | $\text{Yt PO}_4$                                   | Tetragonal   |
| <i>Silicates</i>  | <b>Zircon</b>          | $\text{ZrSiO}_4$                                   | Tetragonal   |
|                   | <i>Thorite</i>         | $\text{ThSiO}_4$                                   | Tetragonal   |
|                   | <i>Cerite</i>          | Hydrated cerium silicate                           | Orthorhombic |
|                   | <i>Gadolinite</i>      | $\text{Yt}_2\text{Be}_2\text{FeSi}_2\text{O}_{10}$ | Monoclinic   |
| <i>Uranate</i>    | <i>Thorianite</i>      | $\text{ThO}_2 \cdot \text{U}_2\text{O}_5$          | Isometric    |

These elements also enter into a large series of silicates, phosphates and niobates, some of which are mentioned in footnotes of the succeeding pages.

*Samaraskite*, *fergusonite*, and *allanite*, are described in this book.

### ECONOMIC IMPORTANCE.

#### Zirconium.

The metal has no uses. The oxide zirconia glows brilliantly when highly heated and is very durable. It is used for coating

the cylinders of the Drummond light and the filament of the Nernst light is chiefly zirconia with less yttria and other rare earths. A recent larger use is as the "opacifier" in the white glass used in indirect electric lighting. The chief source is the Brazilian zirconium oxide. The zircon of Norway and of North and South Carolina were formerly important sources.

The zirconia is made from *zircon*\* or altered zircon (zirconium oxide) by fusing with acid potassium fluoride, extracting with hot water, treating with hydrochloric acid and precipitating with ammonia.

### Thorium.

The metal and its alloys have no economic uses. The oxide, thoria, is very important because of its use in different incandescent gas mantles. The mantle of the Welsbach lamp consists of about 99 per cent. of thoria with one per cent. of ceria.

Thoria is manufactured by methods which are carefully guarded. In practice monazite as it comes into the markets is separated from other impurities which occur in the sand by means of Wetherill magnetic separators. This monazite is then treated with strong sulfuric acid and the thorium later precipitated.

Both *thorite*† and *thorianite* are used for the manufacture of thoria, but the supply is limited.

The chief source is the cerium mineral, *monazite*, of which it is stated about 3000 tons per year are used. Monazite carries salts of thorium as impurities and in quantities varying from traces to as much as 18.5 per cent. of thorium oxide.

Brazil furnishes most of the monazite although Travancore, Madras, in 1912 produced 1,135 tons, containing 14 per cent. thoria and Ceylon 224 lbs. thorianite in 1910.

### Cerium.

Metallic cerium is an important part of the alloy called "Misch metal" made from residues after removal of thoria. It is used as a reducing agent and is said to be the alloy in patent cigar lighters.

The oxide ceria is used in various incandescent mantles and the

---

\* A few of the other species containing zirconium are wöhlerite, eudialite, naegite, zirkelite and lävenite.

† The following minerals also are usually rich in thorium and would be valuable if found in quantity: Thorogummite, mackintoshite, æschynite, zirkelite, tscheffkinite, yttrialite, caryocerite, euxenite, pyrochlore.

fluoride in the flaming arc light. Other compounds are used in making and fixing dyes and in color photography.

*Cerite* is made directly into a crude sulphate used as a catalyst in sulphuric acid manufacture.

The manufacture of the oxide is incidental to the manufacture of thorium. No mineral is used exclusively for making ceria.\* *Monazite* is the principal source.†

### Yttrium.

The oxide yttria,  $Y_2O_3$ , was used in the Nernst lamp filament and in gas mantles.

*Gadolinite*‡ is the chief mineral, though yttria may be recovered in any separation of the groups.

### FORMATION AND OCCURRENCE OF ZIRCONIUM, THORIUM, CERIUM AND YTTRIUM DEPOSITS.

These elements occur in the igneous rocks‡ and certain gneisses. Zirconium is the most plentiful, but cerium and yttrium are estimated at only 0.001 per cent. and thorium at only 0.0001 per cent.

The economic deposits are practically limited to *pegmatites* of granite or syenite, such as those of southern Norway and Sweden or Baringer Hill, Texas and to *residual deposits* such as the monazite sands of Brazil or the gold washings of Henderson County, N. C., and the "zircon favas" (Favas = rounded pebbles) bearing gravels of Minas Geraes, Brazil. A sandstone carrying 12 to 29 per cent. of zircon occurs near Ashland, Va.

### ZIRCONIUM OXIDE.

Zirconium oxide,  $ZrO_2$ , occurs in negligible quantities as the mineral baddeleyite, of which a crystal fragment (monoclinic) was found in the Ceylon gem gravels at Rakwana, and it has been found at Jacupiranga, Brazil, and Alnö, Sweden, in basic (magnetite, pyroxene, chrysolite) rocks. The oxide is, however, found in quantity in the syenite gravels of Serra de Caldas and Rio Verdinho, Minas Geraes, Brazil, as masses of dark, greenish gray color with fibrous concentric "Glaskopf" structure resulting from decomposed zircon and locally known as "Zircon Favas."

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\* A few of the many other species carrying cerium are tysonite, parisite, bastnaesite, mosandrite, tritomite, fluocerite.

† Others are yttrialite, tengerite, xenotime, etc.

‡ Zircon, monazite, allanite and xenotime are most frequently observed.

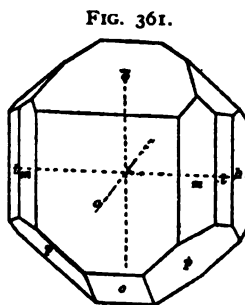
**MONAZITE.**

**COMPOSITION.** —  $(\text{Ce.La.Di})\text{PO}_4$ , but with notable quantities of thorium and silicon and frequently small amounts of erbium and ytterbium.

**GENERAL DESCRIPTION.** — Small, brown, resinous crystals, or yellow, translucent grains, disseminated or as sand. Sometimes in angular masses.

**CRYSTALLIZATION.** — Monoclinic. Axes  $a : b : c = 0.969 : 1 : 0.926$ ;  $\beta = 76^\circ 20'$ . Crystals are usually small and flat, but sometimes large. Fig. 361 shows the pinacoids  $a$  and  $b$ , the unit pyramid, prism and dome  $p$ ,  $m$  and  $o$  and the prism  $l = (2a : b : \infty c)$ ;  $\{120\}$ . Supplement angles  $mm = 86^\circ 34'$ ;  $ad = 39^\circ 12'$ ,  $pp = 73^\circ 19'$ .

**OPTICALLY** +, with axial plane nearly  $a$  and acute bisectrix nearly vertical. Axial angle in red light  $2E = 29^\circ$  to  $31^\circ$ .



**Physical Characters.** — H., 5–5.5. Sp. gr., 4.9–5.3.

LUSTRE, resinous.

OPAQUE, to translucent.

STREAK, white.

TENACITY, brittle.

COLOR, clove or reddish brown, yellow.

CLEAVAGE, basal, perfect.

**BEFORE BLOWPIPE, ETC.** Turns gray when heated, but does not fuse. Is decomposed by hydrochloric acid with a white residue. Solutions added to a nitric acid solution of ammonium molybdate produce a yellow precipitate.

**REMARKS.**—Occurs as crystals in the *pegmatites* of Norway and Sweden, and in large crystals and masses at Amelia County, Va. Disseminated in gneiss in Brazil and in North Carolina and as needles or minute crystals in apatite of Arendal, Norway, Hurdstown, N. J., and elsewhere.

Residual deposits occur in Brazil as sea shore sands near Prado, Bahia, and Esperito Santo, and in beds of gravel in Minas Geraes and elsewhere. Also found in the gold and platinum washings of Siberia, Colombia and in North Carolina (formerly important) and the tin deposits of Malay, Nigeria and Nyassaland.

**XENOTIME.**

**COMPOSITION** —  $\text{YtPO}_4$  ( $\text{Yt}_2\text{O}_3$  54 to 64,  $\text{Ce}_2\text{O}_3$  0 to 11,  $\text{ThO}_2$  0 to 3,  $\text{ZrO}_2$  0 to 2 per cent.).

**GENERAL DESCRIPTION.**—Soft yellow, brown or red crystals, zircon-like in form with easy prismatic cleavage.

CRYSTALLIZATION.—Tetragonal,  $\epsilon = 0.6187$ . Common forms unit prism  $m$ , unit pyramid  $p$ , second order prism  $a$ . Supplement angle  $pp = 55^\circ 30'$ .

PHYSICAL CHARACTERS.—Opaque. Lustre, resinous to vitreous. Color, yellows, browns and flesh red. Streak, paler than color. H., 4 to 5. Sp. gr. 4.45 to 4.56. Cleavage, perfect parallel  $m$ .

BEFORE BLOWPIPE, ETC.—Infusible. Bluish green flame with sulphuric acid. Insoluble in acids.

REMARKS.—Occurrence like monazite in the Swedish pegmatites, and the residual deposits of Brazil and North Carolina. Also in larger crystals at Alexander Co., N. C.

### ZIRCON.—Hyacinth.

COMPOSITION.— $\text{ZrSiO}_4$  (ZrO 67.2,  $\text{SiO}_2$  32.8 per cent.).

GENERAL DESCRIPTION.—Small, sharp cut, square prisms and pyramids with adamantine lustre and brown or grayish color. Sometimes in large crystals and in irregular lumps and grains.

CRYSTALLIZATION.—Tetragonal. Axis  $c = 0.640$ . Common forms: unit prism  $m$ , unit pyramid  $p$ , second order prism  $a$ , and pyramids  $u = (a : a : 3c)$ ;  $\{331\}$  and  $x = (a : 3a : 3c)$ ;  $\{311\}$ . Supplement angles  $pp = 56^\circ 41'$ ;  $uu = 83^\circ 9'$ ;  $mu = 20^\circ 12'$ ;  $ax = 31^\circ 53'$ ;  $mp = 47^\circ 50'$ ;  $pp$  over top  $84^\circ 20'$ .

Optically + with strong refraction and double refraction ( $\alpha = 1.9239$ ;  $\gamma = 1.9628$  for yellow light).

FIG. 362.

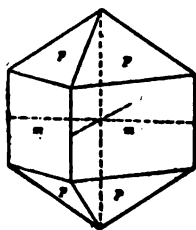


FIG. 363.

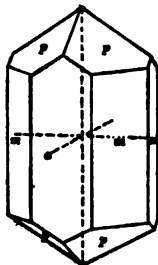


FIG. 364.

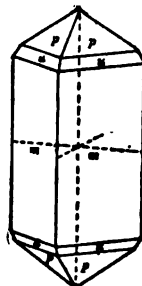
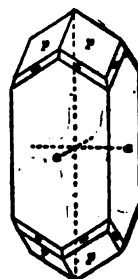


FIG. 365.



Physical Characters. H., 7.5. Sp. gr., 4.68 to 4.70.

LUSTRE, adamantine.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, brown, reddish, gray, colorless, green, yellow.

CLEAVAGES, imperfect, parallel to both pyramid and the prism.

BEFORE BLOWPIPE, ETC.—Infusible, losing color and sometimes becoming white. Insoluble in acids or in soda.

**REMARKS.**—Occurs in minute crystals in granite and especially in nephelite or augite syenite, as in the Wichita Mts., Oklahoma. Larger crystals occur in pegmatites as in Southern Norway, Litchfield, Maine, and Canada. Less common in crystalline schists (Tyrol) and occasionally in beds of iron ore, Mineville, N. Y., and Fredericksvarn, Norway.

Residual deposits often contain zircon as in the gold sands of North Carolina and the gem gravels of Ceylon and Expailly, France.

#### THORITE—Orangite.

**COMPOSITION.**— $\text{ThSiO}_4$ , carrying some water.

**GENERAL DESCRIPTION.**—Black or orange-yellow tetragonal crystals like those of zircon. Also found massive.

**PHYSICAL CHARACTERS.**—Translucent to transparent. Lustre resinous. Color, black, brown and orange. Streak, orange to brown. Brittle. H., 4.5–5. Sp. gr., 4.4–5.2.

**BEFORE BLOWPIPE, ETC.**—Infusible. Gelatinizes with hydrochloric acid before being heated by blowpipe but not after. In closed tube yields water and the orange variety becomes nearly black while hot, but changes to orange again on cooling.

**REMARKS.**—Thorite occurs in large black crystals in a pegmatite near Arendal, Norway, and as masses and crystals of orange color at Lövd and other localities near Brevik, Norway. A mass was found in the Champlain iron region, New York. It occurs in veins in hornblende granite in Sutherland, Scotland, and at the Trotter Mine, New Jersey.

#### CERITE.

**COMPOSITION.**—Hydrated cerium silicate with  $\text{Ce}_2\text{O}_3$  36 to 72,  $\text{Y}_2\text{O}_3$  0 to 7,  $\text{ZrO}_2$  0 to 11 per cent.

**GENERAL DESCRIPTION.**—Granular masses between clove brown and cherry red in color. Rarely crystals. Resembles red granular corundum.

**CRYSTALLIZATION.**—Orthorhombic highly modified short prisms.

**PHYSICAL CHARACTERS.**—Nearly opaque. Luster, dull to resinous. Color, cherry red, brown, gray. Streak, gray or white. H., 5.5. Sp. gr., 4.86.

**BEFORE BLOWPIPE, ETC.**—Infusible. In closed tube yields water. With soda a yellow slag nearly colorless on cooling. Gelatinizes with hydrochloric acid.

**REMARKS.**—Occurs at Bastnäs, Sweden, as a bed in gneiss with allanite, chalcopryrite, and other minerals.

#### GADOLINITE.

**COMPOSITION.**— $\text{Y}_2\text{Be}_2\text{FeSi}_2\text{O}_{10}$  (Yttrium Oxides 51.8,  $\text{BeO}$  10.0,  $\text{FeO}$  14.3,  $\text{SiO}_2$  23.9 per cent.).

**GENERAL DESCRIPTION.**—Rounded or nodular masses, internally glassy and nearly black, externally earthy and reddish or yellow. Somewhat resinous in luster. Sometimes in coarse monoclinic crystals.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, vitreous to greasy. Color, black or greenish black. Streak, greenish gray. H., 6.5 to 7. Sp. gr., 4.24 to 4.47.

**BEFORE BLOWPIPE, ETC.** Infusible but swells and cracks and if glassy glows brightly. Gelatinizes with hydrochloric acid.

**REMARKS.**—Occurs in pegmatite veins. Abundant at Baringer Hill, Llano Co., Texas. Found at Hitterö and Risör, Norway, and Kararfvet and Ytterby, Sweden,



**THORIANITE.**  $\text{ThO}_2\text{U}_2\text{O}_8$  ( $\text{ThO}_2$  70 to 80,  $\text{Ce}_2\text{O}_3$  12 to 28,  $\text{UO}_2$  12 to 25,  $\text{ZrO}_2$  up to 3 per cent.), occurring as small black water worn cubic crystals found in the Ceylon gem gravels. Sp. gr., 9.3.

## THE LEAD MINERALS.

The minerals described are:

|                         |                     |  |                     |
|-------------------------|---------------------|--|---------------------|
| <i>Metal</i>            | <i>Lead</i>         | <i>Pb</i>                              | <i>Isometric</i>    |
| <i>Sulphide</i>         | <i>Galenite</i>     | $\text{PbS}$                           | <i>Isometric</i>    |
| <i>Sulphantimonites</i> | <i>Bournonite</i>   | $\text{PbCuSbS}_3$                     | <i>Orthorhombic</i> |
|                         | <i>Jamesonite</i>   | $\text{Pb}_3\text{Sb}_2\text{S}_6$     | <i>Orthorhombic</i> |
| <i>Selenide</i>         | <i>Clausthalite</i> | $\text{PbSe}$                          | <i>Isometric</i>    |
| <i>Oxide</i>            | <i>Minium</i>       | $\text{Pb}_3\text{O}_4$                |                     |
| <i>Sulphate</i>         | <i>Anglesite</i>    | $\text{PbSO}_4$                        | <i>Orthorhombic</i> |
| <i>Phosphate</i>        | <i>Pyromorphite</i> | $\text{Pb}_3\text{Cl}(\text{PO}_4)_3$  | <i>Hexagonal</i>    |
| <i>Arsenate</i>         | <i>Mimetite</i>     | $\text{Pb}_3\text{Cl}(\text{AsO}_4)_3$ | <i>Hexagonal</i>    |
| <i>Carbonate</i>        | <i>Cerussite</i>    | $\text{PbCO}_3$                        | <i>Orthorhombic</i> |

*Zinkenite*, *plagionite*, *boulangerite*, *geocronite*, *linarite* and *phosgenite* are briefly mentioned. Other lead minerals described elsewhere are *crocoite*, *vanadinite*, *descloizite*, *wulfenite*, and lead is found in many other species.

## ECONOMIC IMPORTANCE.

The world uses about 1,500,000 tons of lead per year, of which this country, in 1915, produced 565,356 tons from domestic ores.\* Of this 221,797 tons was soft lead, mainly produced in Missouri, containing almost no silver and gold. During the same year 317,463 tons of lead was desilverized; indeed, it may be said that by far the most important use of lead ore is to mix and smelt with silver ores, whereby metallic lead containing silver and gold are obtained.

The principal use of metallic lead is in the manufacture of white lead and large amounts are used for the preparation of red lead, litharge, shot, lead pipe and sheet lead. A certain amount of lead containing antimony, 24,370 tons in 1915, is produced which is used in type and in alloys for friction-bearings.

The argentiferous lead ores of the west, which ordinarily run low in lead are smelted in blast-furnaces. The ore, if it contains much sulphur, is roasted, to remove the sulphur and other volatile constituents, and is then fused, forming a silicate, which is

\* *Engineering and Mining Journal*, 1916, p. 56.

charged in the furnace with the proper proportions of fuel and flux (limestone, hematite, etc.). The reduction takes place under the action of the blast. Metallic lead, carrying most of the silver, is produced, and if either sulphur or arsenic is present, a sulphide (matte) and an arsenide (speiss) of iron, copper, etc., will form, and above all these will float the slag composed of the gangue and the flux.

The furnace is usually oblong in section, and the hearth is connected, by a channel from the bottom, with an outer basin or well, so that the metal stands at the same level in each and can easily be ladled out. Above the hearth, and enclosing the smelting zone, are what are called the water jackets, in which cold water circulates. The furnace gases pass through a series of condensing chambers.

The matte, speiss and the dust collected in the condensing chambers are all treated for silver, gold, lead, copper, etc., usually at different works. The metallic lead, or base bullion, is desilverized by remelting in large kettles, raising it to the melting-point of zinc, adding metallic zinc and cooling to a point between the melting-points of zinc and lead. The lighter solidified zinc separates, *carrying with it the silver and gold*, and forms a crust on the surface of the lead, from which it is skimmed.

The lead is further purified and the zinc, gold and silver separated electrolytically or by distillation.

#### FORMATION AND OCCURRENCE OF LEAD DEPOSITS.

The evidence as to the presence of lead minerals as primary constituents of igneous rocks is not very conclusive. Minute amounts have been found in a few analyses. Lead forms no important silicates.\* The great lead deposits appear to be galenite as a primary mineral deposited with other sulphides especially sphalerite

No deposits due to magmatic segregation are known.

#### Vein Deposits.

These are estimated to supply one third of all the lead as opposed to one half in metasomatic replacements.\* Veins are more or

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\* Rare species *barysilite*, *hyalotekite*, *ganomalite*.

† Beyschlag, Vogt & Krusch (Truscott), p. 775.

less directly connected with intrusions of igneous rock and may be in crystalline schists or igneous rocks or the older sediments and are often rich in silver. At Freiberg, Saxony, they are in gneiss, at Clausthal, Harz; and Příbram, Bohemia; in clay slate and graywacke, at Linares, Spain; in granite. Other important veins are at Kapnik, Hungary; Shoshone, Idaho; Cornwall, England.

#### Replacements.\*

Usually in limestone or dolomite as in Missouri, Wisconsin, Illinois and Kentucky; Leadville and Aspen, Colorado; Park City and Tintic, Utah; Eureka, Nevada; Elkhorn, Mont.; Derbyshire and Cumberland, England; Raibl and Bleiberg, Carinthia; Iglesias, Sardinia; Sala, Sweden; and Upper Silesia.

#### Contact Deposits.

The greatest\* lead mine, Broken Hill, New South Wales, was regarded as "saddle lodes,"† p. 328, but is now said to be a contact deposit, the ores intergrown with garnet, rhodonite, etc. Other contact deposits are South Mountain, Idaho, and Magdalen Mines, New Mexico.

#### LEAD.—Native Lead.

COMPOSITION.—Pb, with sometimes a little Sb or Ag.

GENERAL DESCRIPTION.—Usually small plates or scales or globular masses embedded in other minerals. Very rarely in octahedrons or dodecahedrons.

PHYSICAL CHARACTERS.—Opaque. Lustre metallic. Color and streak lead gray. H., 1.5. Sp. gr., 11.37. Malleable.

BEFORE BLOWPIPE, ETC.—Fuses easily, coating charcoal with yellow oxide, and tinging flame light blue. Soluble in dilute nitric acid.

#### GALENITE.—Galena.

COMPOSITION.—PbS (Pb 86.6 per cent.), usually with some silver and frequently sulphide of antimony, bismuth, cadmium, etc.

GENERAL DESCRIPTION.—A soft, heavy, lead-gray mineral, with metallic lustre and easy cubical cleavage. Sometimes in crystals. Rarely fine-grained or fibrous.

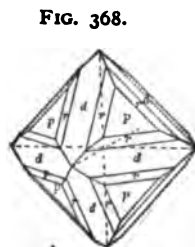
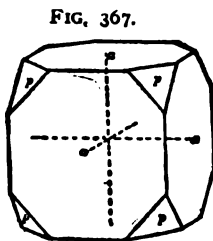
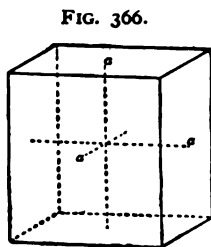
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\* Deposited as simple sulphides, chiefly *galenite* and *sphalerite*, sometimes with *pyrite* and *chalcopyrite*. Later oxidation and weathering forms carbonate, sulphate, phosphate, etc.

\* Said to yield yearly about one ninth of world's production of lead. *Beyschlag*. Vogt and Krusch, p. 1102.

† *Ibid.*, 1173.

**CRYSTALLIZATION.**—Isometric. Usually the cube, Fig. 366, or cubo-octahedron, Fig. 367, sometimes octahedral or showing that rare form the trisoctahedron  $r = (a : a : 2a)$ ;  $\{221\}$ ; Fig. 368. Sometimes twinned or in skeleton crystals or reticulated.



**Physical Characters.**—H., 2.5. Sp. gr., 7.4 to 7.6.

LUSTRE, metallic

OPAQUE.

STREAK, lead-gray.

TENACITY, brittle.

COLOR, lead-gray.

CLEAVAGE, cubic, very easy.

**BEFORE BLOWPIPE, ETC.**—On charcoal decrepitates and fuses easily, yielding in O. F. a white sulphate coat, and in R. F. a yellow coat and metallic button of lead. With bismuth flux, gives a strong iodide coat, which appears chrome-yellow on plaster and greenish-yellow on charcoal. With soda, yields malleable lead and a sulphur test. Soluble in excess of hot hydrochloric acid, from which white lead chloride separates on cooling. Soluble also in strong nitric acid, with separation of sulphur and lead sulphate.

**SIMILAR SPECIES.**—Characterized by its cleavage, weight and appearance, except in some fine-grained varieties.

**REMARKS.**—The occurrences have been described, p. 317. The great producing states in 1914 were Missouri, 192,612; Idaho, 174,263; Utah, 85,622; Colorado, 37,106 (short tons of lead).

**USES.**—It is the chief ore of lead, and as it usually contains silver, the silver-bearing deposits are more frequently worked than the purer galenite, and both the lead and silver are recovered.

#### BOURNONITE.

**COMPOSITION.**— $\text{PbCuSbS}_4$ , (Pb 42.5, Cu 13.0, Sb 24.7, S 19.8 per cent.).

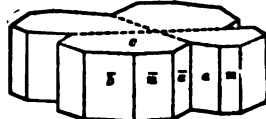
**GENERAL DESCRIPTION.**—A gray metallic mineral, nearer steel-gray than galenite, and occurring fine-grained, massive and in thick tabular crystals, or cross Fig. 370, and "cog-wheel" twins. Supplement angles  $mm = 86^\circ 20'$ ,  $co = 43^\circ 43'$ ,  $cn = 33^\circ 15'$ .

FIG. 369.



Harz.

FIG. 370.



Kapnik.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, metallic. Color, steel-gray to nearly black. Streak, steel-gray. H., 2.5 to 3. Sp. gr., 5.7 to 5.9. Brittle. Cleavages imperfect.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses easily, yielding heavy white sublimate, and later a yellow sublimate. With bismuth flux yields strong greenish-yellow coat on charcoal and a mingling of chrome yellow and peach red on plaster. After sublimates have formed, the residue will color the flame deep green, or if moistened with a drop of hydrochloric acid, will color the flame bright azure blue. Soluble in nitric acid to a green solution, with formation of a white insoluble residue.

**REMARKS.**—Occurs as secondary mineral in veins as at Kapnik, Hungary; Endellion, Cornwall; Reported in Yavapai Co., Arizona.

#### JAMESONITE.—Feather Ore.

**COMPOSITION.**— $\text{Pb}_2\text{Sb}_2\text{S}_4$ . (Pb 50.8, Sb 29.5, S 19.7 per cent.).

**GENERAL DESCRIPTION.**—Steel-gray to dark-gray metallic needle crystals, or hair-like and felted; also compact and fibrous massive.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, metallic. Color, steel-gray to dark-lead gray. Streak, grayish-black. H., 2 to 3. Sp. gr., 5.5 to 6. Brittle.

**BEFORE BLOWPIPE, ETC.**—Decrepitates and fuses very easily, and is volatilized, coating the charcoal white and yellow as in bournonite. With bismuth flux, reacts like bournonite. In closed tube, yields dark-red sublimate, nearly black while hot. Soluble in hot hydrochloric acid, with effervescence of hydrogen sulphide.

**REMARKS.**—Secondary in veins with stibnite as at Freiberg, Saxony, and Sevier Co., Arkansas; or with galenite as at Przibram. In Zimapan, Mexico, occurs in commercial quantity.

The following four species are representative of a series of secondary minerals formed in lead and antimony veins. In blowpipe characters all are like jamesonite. Hardness, 2.5 to 3.5. The specific gravity, 5.3 to 6.5, increases with the lead.

**ZINKENITE.**— $\text{PbS.Sb}_2\text{S}_4$ . Columnar and fibrous steel-gray material from Wolfsberg, Harz, Sevier Co., Ark., etc.

**PLAGIONITE.**— $5\text{PbS.4Sb}_2\text{S}_4$ . Druses of short thick notably oblique (monoclinic) crystals of dark lead gray color from Wolfach, Baden; Wolfsberg, Harz, etc.

**BOULANGERITE.**— $3\text{PbS.Sb}_2\text{S}_4$ . Feathery masses and needle crystals of bluish lead gray color, often covered with yellow spots due to oxidation.

From Echo District, Nevada; Bottino, Tuscany, etc.

**GEOCRONITE.**— $5\text{PbS.Sb}_2\text{S}_4$ . Light lead gray massive granular material from Sala, Sweden and Inyo Co., Calif.

### CLAUSTHALITE.

COMPOSITION.— $\text{PbSe}$ , (Pb 72.4, Se 27.6 per cent.). Many contain silver or cobalt.

GENERAL DESCRIPTION.—Bluish gray fine granular masses of metallic lustre. Rarely foliated. Resembles galenite.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, bluish lead gray. Streak, grayish black. H., 2.5 to 3. Sp. gr., 7.6 to 8.8.

BEFORE BLOWPIPE, ETC.—On charcoal fuses and yields odor like decayed horse-radish, coats the charcoal with a white sublimate with red border, and later a yellow coat forms. In open tube gives a red sublimate. With soda yields a mass which blackens silver.

### MINIUM.

COMPOSITION.— $\text{Pb}_3\text{O}_4$ . (Pb 90.6 per cent.).

GENERAL DESCRIPTION.—A vivid red powder or loosely compacted mass of dull or greasy lustre. Often intermixed with yellow.

PHYSICAL CHARACTERS.—Opaque. Bright red. Lustre, dull or greasy. Streak, orange yellow. H., 2 to 3. Sp. gr., 4.6.

BEFORE BLOWPIPE, ETC.—Is reduced to metallic lead, and yields the characteristic lead sublimate.

REMARKS.—The artificial product is the red lead of commerce. Chiefly an alteration of galenite or cerussite, sometimes pseudomorphous after them. Occurs Wythe Co., Virginia; Leadhills, Scotland; Bleiberg, Eifel; Brilon, Westphalia, etc.

### ANGLESITE.

COMPOSITION.— $\text{PbSO}_4$ , (PbO 73.6,  $\text{SO}_3$  26.4 per cent.).

GENERAL DESCRIPTION.—Simple crystals, often transparent and colorless, white brittle masses and compact granular masses of gray color from intermixed galenite. Sometimes in concentric layers around a core of unaltered galenite.

FIG. 371.

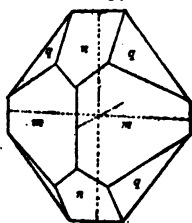
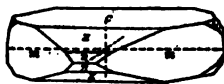


FIG. 372.



Phoenixville, Pa.

CRYSTALLIZATION.—Orthorhombic. Axes  $a : b : c = 0.785 : 1 : 1.289$ . Crystals vary greatly in type, but are rarely twinned. Unit prism  $m$  and domes such as  $n = (a : \infty b : \frac{1}{2}c)$ ;  $\{102\}$ ;  $z = (a : \infty b : \frac{1}{4}c)$ ;  $\{104\}$ ; and pyramids  $q = (2a : b : c)$ ;  $\{122\}$  are frequent.

Supplement angles:  $mm = 76^\circ 17'$ ;  $cn = 33^\circ 24'$ ;  $cz = 22^\circ 19'$ ;  $cq = 56^\circ 48'$ .

**Physical Characters.** H., 3. Sp. gr., 6.12 to 6.39.

LUSTRE, adamantine to vitreous. TRANSPARENT to opaque.

STREAK, white.

TENACITY, very brittle.

COLOR, colorless, white, gray; rarely yellow, blue or green.

CLEAVAGE, basal and prismatic ( $90^\circ$  and  $103^\circ 43'$ ).

BEFORE BLOWPIPE, ETC.—On charcoal decrepitates and fuses easily to a glassy globule pearly white on cooling. In R. F. is reduced and yields metallic lead and the yellow sublimate. With soda yields the sulphur reaction. Insoluble in hydrochloric acid but is converted into chloride. Slowly soluble in nitric acid.

SIMILAR SPECIES.—It differs from the carbonate, cerussite, in absence of twinned crystals and of effervescence in acids. It is heavier than barite and celestite, and yields lead.

REMARKS.—Anglesite is formed by the oxidation of galenite and found wherever exposed deposits of galenite occur. Large quantities have been found in Sierra Mojada, Mexico; Leadville, Colorado; Cerro Gordo, California; Yuma Co., Arizona. An earthy variety occurs near Coquimbo, Chili. Famous localities for crystals are Monte Ponì Sardinia; Wheatley's Mine, Pennsylvania; Anglesey, England and Felsobanya, Hungary.

LINARITE.— $[(\text{PbCu})\text{OH}]_2\text{SO}_4$ . In small, deep blue, monoclinic crystals.

### PYROMORPHITE.

COMPOSITION.— $\text{Pb}_5\text{Cl}(\text{PO}_4)_3$ , (PbO 82.2,  $\text{P}_2\text{O}_5$  15.7, Cl 2.6 per cent.) often with some As, Fe or Ca.

GENERAL DESCRIPTION.—Short hexagonal prisms and branching and tapering groups of prisms in parallel position. The color is most frequently green, brown, or gray. Also in moss-like interlaced fibers and masses of imperfectly developed crystals. Less frequently in globular and reniform masses.

CRYSTALLIZATION.—Hexagonal, class of third order pyramid, p. 57.

Axis  $c = 0.736$ . Usual form prism  $m$  and base  $c$ . Faces  $m$  horizontally striated, sometimes tapering.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 5.9 to 7.1.

LUSTRE, resinous.

TRANSLUCENT to opaque.

STREAK, white to pale yellow.

TENACITY, brittle.

COLOR, green, gray, brown; also yellow, orange, white.

BEFORE BLOWPIPE, ETC.—On charcoal fuses to a globule which on cooling does not retain its globular form but crystallizes, show-

ing plane faces. In reducing flame yields white coat at a distance and yellow coat nearer the assay, and a brittle globule of lead. In closed tube with magnesium ribbon yields a phosphide which, moistened with water, evolves phosphine. With salt of phosphorus saturated with copper oxide yields an azure blue flame. Soluble in nitric acid, and from the solution ammonium molybdate throws down a yellow precipitate.

**SIMILAR SPECIES.**—Differs from other lead minerals in fusing to a crystalline globule without reduction.

**REMARKS.**—A decomposition product of galenite and other lead minerals occurring near the outcrop and sometimes in sufficient quantities to be smelted. Found at Phoenixville, Pa., Davidson county, N. C., Lenox, Me., Cour d'Alene, Idaho, and in many foreign localities, notably Huelgoet, Brittany; Ems, Nassau; Berezov, Siberia; Cornwall, Derbyshire and Cumberland, England; Leadhills, Scotland.

**MIMETITE.**— $3\text{Pb}_3(\text{AsO}_4)_2 + \text{PbCl}_2$  or  $\text{Pb}_2\text{Cl}(\text{AsO}_4)_2$ , often with some replacement by P or Ca.

Pale yellow to brown hexagonal prisms or globular groups of crystals. Sometimes incrusting. Streak, white. H., 3.5. Sp. gr., 7.0 to 7.25, lower when Ca is present.

On charcoal fuses easily and is reduced to metallic lead, coating the coal with white and yellow sublimes and yielding strong arsenical odor. Found in Cumberland, England; Cerro Gordo, Calif.; Yuma Co., Arizona, etc.

### CERUSSITE.—White Lead Ore.

**COMPOSITION.**— $\text{PbCO}_3$ , (PbO, 83.5;  $\text{CO}_2$ , 16.5 per cent.). Often carries silver.

**GENERAL DESCRIPTION.**—Very brittle, white or colorless orthorhombic crystals; silky, milk-white masses of interlaced fibres; granular, translucent, gray masses and compact or earthy, opaque masses of yellow, brown, etc., colors.

FIG. 373.

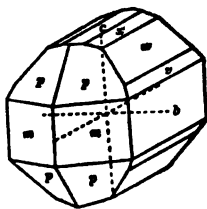
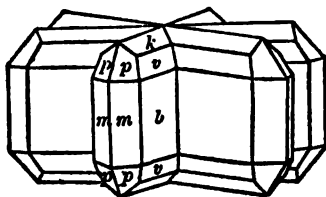


FIG. 374.



**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.610 : 1 : 0.723$ . Common forms: unit pyramid  $p$ , and prism  $m$  and a series of brachy domes such as  $x = (\infty a : b : \frac{1}{2}c)$ ;  $\{012\}$ ;  $w = (\infty a :$



$\bar{b} : 2c$ );  $\{021\}$  and  $v = (\infty a : \bar{b} : 3c)$ ;  $\{031\}$ . Frequently twinned about  $m$  sometimes yielding six-rayed groups as in Fig. 374. Supplement angles are  $mm = 62^\circ 46'$ ,  $pp = 50^\circ$ ,  $ww = 110^\circ 40'$ .

**Physical Characters.**—H., 3 to 3.5. Sp. gr., 6.46 to 6.51.

LUSTRE, adamantine, silky. TRANSPARENT or translucent.

STREAK, white. TENACITY, very brittle.

COLOR, white, gray, colorless or colored by impurities.

CLEAVAGES, parallel to prism and brachy dome.

BEFORE BLOWPIPE, ETC.—On charcoal, decrepitates, fuses and gives a yellow coating, and finally a metallic globule. In closed tube, turns yellow, then dark, and on cooling is yellow. Effervesces in acids, but with hydrochloric or sulphuric acid leaves a white residue.

SIMILAR SPECIES.—Distinguished from anglesite by effervescence in acids and by frequent occurrence of twinned crystals. Has higher specific gravity than most carbonates.

REMARKS.—Found in the oxidized zone of lead deposits. Formerly the principal mineral of the Leadville, Colorado deposits and in large masses in Pima Co., Arizona. Now abundant at Cour d'Alene, Idaho; Cerro Gordo, California, and especially Broken Hill, New South Wales.

PHOSGENITE.— $Pb_2Cl_2CO_2$ . In transparent, colorless or gray tetragonal crystals.

### THE BISMUTH MINERALS.

The minerals described are:

|                  |                     |                    |              |
|------------------|---------------------|--------------------|--------------|
| <i>Metal</i>     | <i>Bismuth</i>      | Bi                 | Hexagonal    |
| <i>Sulphide</i>  | <i>Bismuthinite</i> | $Bi_2S_3$          | Orthorhombic |
| <i>Telluride</i> | <i>Tetradymite</i>  | $Bi_2(Te.S)_3$     | Hexagonal    |
| <i>Carbonate</i> | <i>Bismutite</i>    | $(BiO)_2CO_3.H_2O$ |              |
| <i>Oxide</i>     | <i>Bismite</i>      | $Bi_2O_3$          | Orthorhombic |

Bismuth is the metallic element in other species such as *pucherite*, *eulytite*, *cheleutite*, and *aikinite*, and a constituent of a series of so-called sulpho-bismutites.\*

### ECONOMIC IMPORTANCE.

The important ores are *bismuthinite*, *bismuth* and *bismite*. The world's supply comes chiefly from Bolivia, the principal company producing 437 tons in 1914 and this country following with 110, tons obtained entirely as a by-product in electrolytic lead refining,

\* Such as chiviatite, cuprobismutite, emplectite, matildite and klaprotholite.

largely from unidentified species, and Peru and Australia supplying the rest.

The uses of bismuth are chiefly dependent upon its property of forming easily fusible alloys with other metals, especially tin, lead, and cadmium. These alloys expand in cooling, and are therefore used in type metal, in reproducing woodcuts, in making safety plugs for boilers, etc. Also in anti-friction metals and pewter. The salts of bismuth have numerous uses in medicine and in the arts, are used in calico printing, cosmetics, as pigments, in making glass of high refractive power, and to impart lustre to porcelain.

In Saxony the ores are first roasted to free them from sulphur, arsenic and other volatile constituents. After roasting they are smelted in crucibles with iron, charcoal and slag, the melted bismuth settling out in the bottom of the crucible; or the roasted ores may be treated with strong hydrochloric acid (1 : 1) which dissolves the bismuth and from which it is precipitated as oxychloride by the addition of water. The metal may be further purified electrolytically. When bismuth is found to be present in the cupellation of lead ore, it is recovered by saving the last products of oxidation. From this by solution in hot hydrochloric acid and precipitation as oxychloride the bismuth may be recovered. More recently† the cupellation slag is fused with sodium sulphate and carbon at about 1500° C. giving three layers bismuth, copper matte, and soda slag.

#### FORMATION AND OCCURRENCE OF BISMUTH DEPOSITS.

##### Veins.

The usual occurrence is in veins as in the cobalt bismuth veins at Schneeberg, Saxony, the silver cobalt veins of Joachimsthal, Bohemia, the tin silver veins of Bolivia, and various gold veins.

##### Pegmatites.

Bismuth in quantity may also occur in pegmatites as in New South Wales.

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\* Eng. & Min. Journ. 1916, p. 82.

† Mineral Resources U. S., 1914.

‡ U. S. Patent 1,098,854.

**BISMUTH.—Native Bismuth.**

**COMPOSITION.**—Bi, often alloyed with As or impure from S or Te.

**GENERAL DESCRIPTION.**—A brittle silver-white mineral with a reddish tinge, often in branching shapes or in isolated grains or cleavable masses.

**Physical Characters.** H., 2 to 2.5. Sp. gr., 9.7 to 9.83.

LUSTRE, metallic.

OPAQUE.

STREAK, silver white.

TENACITY, sectile to brittle.

COLOR, reddish silver white.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily and volatilizes completely, coating the charcoal with a yellow sublimate. With bismuth flux forms a chocolate brown and red coating which is best seen on plaster, and which is changed by action of ammonia fumes to red and orange. Soluble in strong nitric acid from which solution water will precipitate a white basic salt.

**SIMILAR SPECIES.**—Bismuth is characterized by its silver streak, reddish tinge, and arborescent structure.

**REMARKS.**—Bismuth in economic quantity is found in the tin silver veins of Tasmania and Chorolque, Bolivia, in a gold-bearing magnetite in Queensland, Australia, in a pegmatite in New England district, New South Wales and in the silver, cobalt and tin veins of Saxony and Bohemia. The metal is not found in any quantity in the United States, although obtained at Monroe, Conn., Colorado, in Inyo Co., California, and in Chesterfield district, South Carolina.

**BISMUTHINITE.**

**COMPOSITION.**— $\text{Bi}_2\text{S}_3$  (Bi 81.2, S 18.8 per cent.). May contain Cu or Fe.

**GENERAL DESCRIPTION.**—A lead gray mineral of metallic lustre usually occurring in foliated or cleavable masses, or in groups of long needle-like orthorhombic crystals.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, metallic. Color, lead gray or lighter, often with yellow tarnish. Streak, lead gray. H., 2. Sp. gr., 6.4 to 6.5. Slightly sectile.

**BEFORE BLOWPIPE, ETC.**—On charcoal yields some sulphur, fuses easily with spirting, and coats the coal with white and yellow sublimates. Yields the characteristic bismuth reactions with bismuth flux and with nitric acid as described under bismuth. With soda gives sulphur reaction.

**REMARKS.**—Bismuthinite occurs in the tin veins of Bolivia and Cornwall, in a pegmatite in New England district, New South Wales, in hornstone at Wolfach, Baden, and in Meymac, France. In this country at Beaver Co., Utah, and Inyo Co., California.

**TETRADYMITES.**

**COMPOSITION.**— $\text{Bi}_2(\text{Te.S})_3$  or  $\text{BiTeS}$ . Either an alloy or a telluride of bismuth.

**GENERAL DESCRIPTION.**—Very soft, flexible, foliated masses of steel-gray color

and bright metallic lustre, or small indistinct rhombohedral crystals. Will mark paper like graphite.

**PHYSICAL CHARACTERS, ETC.**—Opaque. Lustre, metallic. Color, pale steel-gray. Streak, gray. H., 1.5 to 2. Sp. gr., 7.2 to 7.6. Flexible in laminae. Cleavage, basal.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily and is completely volatilized, yielding a white fusible sublimate, followed by a yellow sublimate. The flame during fusion is colored blue. The white sublimate if placed on porcelain and moistened with concentrated sulphuric acid becomes rose colored. If dropped into boiling concentrated sulphuric acid a deep violet color is produced.

**REMARKS.**—Occurs especially in gold veins or with gold as at Schubkau, Hungary; Orawitza, Banat; Tellemark, Norway, and in this country in Virginia, North and South Carolina, Georgia and Montana. In quartz with gold in Arizona.

#### BISMUTITE.

**COMPOSITION.**— $(\text{BiO})_2\text{CO}_3$ ,  $\text{H}_2\text{O}$ , variable.

**GENERAL DESCRIPTION.**—A light colored incrustation or earthy mass or powder.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, dull or vitreous. Color, white, green and yellow. Streak, colorless to greenish. H., 4–4.5. Sp. gr., 6.9–7.7. Tenacity, brittle.

**BEFORE BLOWPIPE, ETC.**—Fuses easily on charcoal, giving a yellow coat and in R. F. a metallic globule which completely volatilizes. With bismuth flux on plaster gives brown and red coat. Yields water in closed tube and decrepitates. Soluble with effervescence in strong HCl, and on dilution with much water the white oxychloride of bismuth is precipitated.

**REMARKS.**—It is usually associated with metallic bismuth or the sulphide and occurs at Brewer's Mine, S. C., Phoenix, Arizona, Inyo Co., Calif.

#### BISMITE.—Bismuth Ochre.

**COMPOSITION.**— $\text{Bi}_2\text{O}_3$ , Bi 89.6 per cent. when pure.

**GENERAL DESCRIPTION.**—A yellowish or gray powder or earthy mass.

**PHYSICAL CHARACTERS.**—Opaque. Color, grayish, greenish or yellowish white. Lustre, dull.

**BEFORE BLOWPIPE, ETC.**—As for bismutite but does not effervesce with acids nor yield water in closed tube.

**REMARKS.**—The 400 ft thick "gossan" of the Schneeberg mines contains much bismite. It forms part of the bismuth at Bamford, Australia, and several mines in Colorado but in general is only a coating on other bismuth species.

### THE ARSENIC MINERALS.

The minerals described are:

|                      |                     |                         |              |
|----------------------|---------------------|-------------------------|--------------|
| <i>Metal</i>         | <i>Arsenic</i>      | As                      | Hexagonal    |
| <i>Sulphides</i>     | <i>Orpiment</i>     | $\text{As}_2\text{S}_3$ | Orthorhombic |
|                      | <i>Realgar</i>      | $\text{As}_2\text{S}_2$ | Monoclinic   |
| <i>Sulpharsenide</i> | <i>Arsenopyrite</i> | $\text{FeAsS}$          | Orthorhombic |
| <i>Arsenide</i>      | <i>Löllingite</i>   | $\text{FeAs}_2$         | "            |

Other species in which arsenic is an essential constituent are:

*niccolite, mimetite, olivenite, smaltite, enargite, proustite, cobaltite, tennantite, and sperrylite.*

#### ECONOMIC IMPORTANCE.

*Arsenopyrite* and *löllingite* are sometimes mined for their arsenic but to a very great extent arsenic is obtained as a by-product in the roasting of ores of other elements such as the cobalt ores of Ontario and certain copper, silver and tin ores.

The world's production of "white arsenic,"  $\text{As}_2\text{O}_3$ , is possibly 100,000 metric tons,† France being the great producer and Germany and this country following. In 1914 this country produced 4,670 short tons‡ and imported 1,600.

Metallic arsenic is ordinarily produced by sublimation from a mixture of the oxide and charcoal, but may be produced by sublimation at a high heat directly from *arsenopyrite* out of contact with air. It is a constituent of some useful alloys, shot metal being the chief.

The poisonous oxide commonly known as arsenic or white arsenic, is produced in large quantities by the roasting of *arsenopyrite* and other arsenical ores and as a by-product in the preparation of tin, silver, nickel and copper. It is used in dyeing, in medicine, in sheep washing, in calico printing, as a preservative for timber and for natural history specimens, in the manufacture of fly paper, and rat poisons, and in glass manufacture. Many important coloring matters as well as the artificial red and yellow sulphides are commercial products. Paris green is an arsenate of copper extensively used as an insecticide.

#### FORMATION AND OCCURRENCE OF ARSENIC DEPOSITS.

There are no known§ metasomatic replacements of *arsenopyrite* or other arsenic minerals.

#### Veins.

(*Arsenopyrite, löllingite orpiment, realgar.*) *Arsenopyrite* as at the Devon Great Consol. Mine, and carrying gold as in the Saddle

\* Others are *gersdorffite, rammelsbergite, skutterudite.*

† Statistics (incomplete) 1912 gives total of 94,699 metric tons, of which France produced 81,880. *Mineral Industry*, 1915, p. 50.

‡ Mineral Resources U. S., 1914.

§ Beyschlag, Vogt & Krusch (Truscott), p. 923.

lodes of Bendigo, West Australia, and Deloro, Canada. Realgar and orpiment as at Kapnik, Hungary.

#### Contacts.

The gold-bearing *löllingite* and *arsenopyrite* of Riechenstein, Silesia, occur as irregular lenses in highly altered tourmaline-bearing schists, the *löllingite* intergrown with contact minerals such as *diopside*, *vesuvianite*, *titanite*, *fluorite*.

*Orpiment* and *realgar* are also stated\* to occur in contacts.

#### ARSENIC.—Native Arsenic.

COMPOSITION.—As, generally with some Sb and sometimes with Bi or a little Co, Ni, Fe, Ag or Au.

GENERAL DESCRIPTION.—A tin-white metal, tarnishing almost black. Usually granular, massive, with reniform surfaces. Can frequently be separated in concentric layers. Rarely found in needle-like crystals.

PHYSICAL CHARACTERS.—Opaque. Lustre, nearly metallic. Color, tin white, tarnishing nearly black. Streak, tin white. H., 3.5. Sp. gr., 5.63 to 5.73. Brittle. Granular fracture.

BEFORE BLOWPIPE, ETC.—On charcoal, volatilizes without fusion, yielding strong garlic odor, white fumes, crystalline white sublimate and pale blue flame. May leave a residue of impurities.

REMARKS.—Principally as a minor constituent of silver or cobalt-nickel veins as in many mines in Saxony, Bohemia and the Harz, the silver veins of Kongsberg, Norway; Chafarcillo, Chili; and Hidalgo, Mexico. It was found also in pockets in dolomitic limestone in Santa Cruz Co., Arizona; and in a vein in a quarry near Montreal.

#### REALGAR.

COMPOSITION.—As<sub>2</sub>S<sub>2</sub>, (As, 70.1; S, 29.9 per cent.).

GENERAL DESCRIPTION.—A soft, orange-red mineral, of resinous lustre, usually occurring in translucent, granular masses, but also compact and in transparent monoclinic crystals.

Physical Characters. H., 1.5 to 2. Sp. gr., 3.4 to 3.6.

LUSTRE, resinous.

TRANSLUCENT to transparent.

STREAK, orange red.

TENACITY, slightly sectile.

COLOR, aurora red, becoming orange yellow on long exposure.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses easily, burns with a blue flame, yields white fumes, with garlic odor and also odor of sulphur dioxide and is volatilized completely. In closed tube yields red sublimate. Soluble in nitric acid, with separation of sulphur. Soluble also in potassium hydroxide from which hydrochloric acid precipitates yellow flakes.

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\* Ibid., 111.

REMARKS.—Occurs with orpiment and sometimes with cinnabar as a deposit from hot springs, as in the Yellowstone, also in ore veins as at Kapnik, Hungary, and Schneeberg, Saxony.

### ORPIMENT.

COMPOSITION.— $\text{As}_2\text{S}_3$ , (As, 61; S, 39 per cent.).

GENERAL DESCRIPTION.—Lemon-yellow, foliated masses, which cleave into thin, pearly, flexible scales, and also granular masses like yolk of hard-boiled eggs. Less frequently as reniform crusts and imperfect orthorhombic crystals.

Physical Characters. H., 1.5 to 2. Sp. gr., 3.4 to 3.6.

LUSTRE, resinous or pearly. TRANSLUCENT to nearly opaque.

STREAK, lemon yellow. TENACITY, slightly sectile.

COLOR, lemon yellow. CLEAVAGE, in plates or leaves.

BEFORE BLOWPIPE, ETC.—As for realgar, except that the sublimate in closed tube is yellow.

REMARKS.—Often formed by alteration of realgar in air and sunlight and found with it both in ore veins as at Kapnik and Felsőbánya, Hungary, and in clay as at Tajowa, Hungary, and Tooele and Iron Counties, Utah. Also a sublimation product near Naples or deposited from hot water as at Steamboat Springs, Nevada. Other occurrences are in brown coal in Styria, in gypsum in Hall, Tyrol. Foliated masses occur at Moldawa, Banat.

### ARSENOPYRITE.—Mispickel.

COMPOSITION.— $\text{FeAsS}$ . (Fe 34.4, As 46.0, S 19.6 per cent.) sometimes with replacement of iron by cobalt, or arsenic by antimony in part.

GENERAL DESCRIPTION.—Silver white to gray mineral with metallic lustre. Usually compact or in granular masses or disseminated grains. Less frequently in orthorhombic crystals or columnar.

CRYSTALLIZATION.—Orthorhombic  $a : b : c = 0.677 : 1 : 1.188$ . Common forms, unit prism  $m$  combined with a brachy dome either  $d = (\infty a : \bar{b} : c)$ ;  $\{011\}$  or  $e = (\infty a : b : \frac{1}{2}c)$ ;  $\{014\}$ . Crossed twins, Fig. 377, occur and fivelings, as in Fig. 197 of marcasite.

Supplement angles  $mm = 68^\circ 13'$ ,  $dd = 99^\circ 50'$ ,  $ee = 33^\circ 05'$ .

Physical Characters. H., 5.5 to 6. Sp. gr., 6 to 6.2.

LUSTRE, metallic.

OPAQUE.

STREAK, grayish-black.

TENACITY, brittle.

COLOR, silver white to steel gray.

**BEFORE BLOWPIPE, ETC.**—Strikes fire with steel and yields an odor like that of garlic. In closed tube a red sublimate, yellow when cold, on longer treatment a black sublimate. On charcoal yields abundant white fumes and arsenical odor and coating and fuses to a magnetic globule. After short treatment the residue is

FIG. 375.

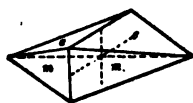


FIG. 376.

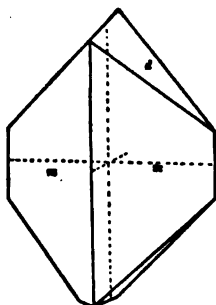
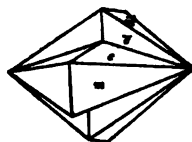


FIG. 377.



soluble in hydrochloric acid with evolution of hydrogen sulphide and precipitation of the yellow sulphide of arsenic. The residue may react for cobalt. Insoluble in hydrochloric acid. Soluble in nitric acid with separation of sulphur.

**SIMILAR SPECIES.**—Massive varieties of the metallic cobalt minerals and varieties of leucopyrite resemble arsenopyrite but are safely distinguished by blowpipe tests, especially the closed tube test.

**REMARKS.**—Arsenopyrite is found chiefly in crystalline schists and the veins which penetrate them associated with ores of silver, cobalt, tin, zinc, etc. Frequently gold-bearing and worked as gold ore as at Deloro, Canada; Passagem, Brazil; and localities in New South Wales. Sometimes carries cobalt (New England) or nickel (Bolivia) and sometimes is in quantity sufficient to be mined for its arsenic (Great Consols Mine, Devonshire).

#### **LÖLLINGITE.—Leucopyrite.**

**COMPOSITION.**— $\text{Fe}_2\text{As}_4$  to  $\text{FeAs}_2$  sometimes with Co, Ni, Au or S.

**GENERAL DESCRIPTION.**—Massive silver-white or gray metallic mineral sometimes occurring in orthorhombic crystals, closely agreeing in angles with crystals of arsenopyrite.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, metallic. Color, silver-white or gray. Streak, grayish-black. H., 5 to 5.5. Sp gr., 7 to 7.4. Brittle. Cleavage, basal.

**BEFORE BLOWPIPE, ETC.**—Like arsenopyrite, except that sulphur reactions are less pronounced or do not appear at all.

**REMARKS.**—Löllingite is the principal mineral at Reichenstein, Silesia, and is mined for its arsenic.



### THE ANTIMONY MINERALS.

The minerals described are:

|                  |                       |                   |              |
|------------------|-----------------------|-------------------|--------------|
| <i>Metal</i>     | <i>Antimony</i>       | Sb                | Hexagonal    |
| <i>Sulphides</i> | <i>Stibnite</i>       | $Sb_2S_3$         | Orthorhombic |
|                  | <i>Kermesite</i>      | $Sb_2S_5O$        | Monoclinic   |
| <i>Oxides</i>    | <i>Valentinite</i>    | $Sb_2O_3$         | Orthorhombic |
|                  | <i>Senarmontite</i>   | $Sb_2O_3$         | Isometric    |
|                  | <i>Antimony Ochre</i> | $Sb_2O_3 + nH_2O$ |              |

Other species containing antimony are numerous, especially compounds with lead and sulphur. Species described elsewhere\* are *jamesonite*, *bourbonite*, *tetrahedrite*, *livingstonite*, *pyrargyrite*, *stephanite*, *dyscrasite*.

#### ECONOMIC IMPORTANCE.

The world production of metallic antimony is about 25,000 tons per year, principally† from China and France. In addition to this there is a considerable production of antimonial lead.

In 1914 no metallic antimony was produced directly in this country but 2,705 tons either in antimonial lead or as a by-product in refining copper. In 1915‡ owing to increased demands some smelters were working on ore from Alaska, Mexico and California.

The principal use of antimony is in hardening alloys of lead, etc., such as type metal, pewter and babbitt metal. Both the metal and the oxide are used in making flint glass. The sulphide is used in vulcanizing rubber, and in safety matches, percussion caps and fireworks, and there are numerous uses for different salts such as "tartar emetic" in medicine and others in pigments and dyes.

In smelting, the ore is heated and the melted sulphide drained off. The sulphide may then be roasted, forming the oxide, which is easily reduced by fusion with charcoal, or more frequently the sulphide is mixed with wrought-iron scraps and salt, placed in a crucible or furnace and fused. The iron combines with the sulphur and the metallic antimony settles to the bottom.

In a later method the sulphide ore and oxysulphide residue

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\* Others are *volgerite*, *guejarite*, *berthierite*, *nadorite*, etc.

† In 1910, 20,536 metric tons of which China produced 13,032, France 6,390, Hungary 1,038. *Mineral Industry*, 1914, p. 47.

‡ *Engineering and Mining Journal*, 1916, p. 79.

from a former operation are treated by a blast of air in a converter. The sulphide becomes volatile oxysulphide and is carried off and condensed. Some metallic antimony is tapped and the oxysulphide is subsequently distilled with a reducing agent.

#### THE FORMATION AND OCCURRENCE OF ANTIMONY DEPOSITS.

There are no great antimony deposits.\* Most frequently the occurrence is in narrow veins of little depth in or near eruptive rocks and there are a few metasomatic replacements and some beds of disputed origin.

The usual primary mineral is *stibnite* which may be auriferous and the usual oxidized product *antimony ochre*, though in the Algerian deposits *senarmonite* and *valentinite* predominate.

#### Veins.

In central France are many narrow veins of *stibnite* which sometimes widen into lenses, as at Freycenet, Puy de Dome; La Lincoulne is a prominent locality. The veins are in granite, gneiss, mica schist, graywacke, etc.

The veins of Iyo and Sujo, Japan, are in schists and sometimes in sediments near contacts with quartz porphyry.

#### Replacements.

At Allkhar, Macedonia, a body of solid *stibnite* without gangue replaces dolomite. Near the surface it is *antimony ochre*.

The beds of *senarmonite* with a little *stibnite* and some zinc and lead minerals at Djebel-Hamimat and Sidi Rgheiss, Algeria; are conformable to the containing beds of limestone and marl and have been called sedimentary but are thought to be replacements.†

#### Ore Beds.

*Stibnite* with *jamesonite*, *zinkenite*, etc., occurs in Sevier Co., Arkansas, in lenticular masses in sandstone and marl.

#### ANTIMONY.—Native Antimony.

COMPOSITION.—Sb, sometimes with As, Fe or Ag.

GENERAL DESCRIPTION.—A very brittle, tin-white metal, usually massive, with fine, granular, steel-like texture or lamellar or radiated. Very rarely in rhombohedral crystals or complex groups.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color, tin white. Streak tin white. H., 3 to 3.5. Sp. gr., 6.5 to 6.72. Very brittle.

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\* Beyschlag, Vogt and Krusch (Truscott), 777.

† Ibid., 1190.

**BEFORE BLOWPIPE, ETC.**—Fuses very easily, colors the flame pale green, gives copious white fumes, which continue to form as a thick cloud after cessation of blast, and often yield a crust of needle-like crystals.

**REMARKS.**—Antimony to the amount of at least a ton was found in a quartz stibnite vein in argillite slate in Prince William, New Brunswick. Small amounts occur in Kern Co., California, and in Andreasberg, Harz; Allemont, France; Huasco, Chili; Sarawak, Borneo, and other localities.

### STIBNITE.—Gray Antimony.

**COMPOSITION.**— $\text{Sb}_2\text{S}_3$ , (Sb 71.8, S 28.2 per cent.). Sometimes contains silver or gold.

**GENERAL DESCRIPTION.**—A lead-gray mineral of bright metallic lustre, occurring in imperfectly crystallized masses, with columnar or bladed structure; less frequently in distinct, prismatic, orthorhombic crystals or confusedly interlaced bunches of needle-like crystals; also in granular to compact masses.

**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.993 : 1 : 1.018$ . Prismatic forms, often bent and curved or in divergent groups. The vertical planes are striated longitudinally.

Common forms: unit prism  $m$ , unit pyramid  $p$  and pyramid  $s = (a : b : \frac{1}{3}c) : \{113\}$ . Supplement angles  $mm = 89^\circ 34'$ ;  $pp = 70^\circ 48'$ ;  $ss = 35^\circ 36'$ .

**Physical Characters.** H., 2. Sp. gr., 4.52 to 4.62.

LUSTRE, metallic.

OPAQUE.

STREAK, lead gray.

TENACITY, brittle to sectile.

COLOR, lead gray, often with black or iridescent tarnish.

CLEAVAGE, easy, parallel to brachy pinacoid, yielding slightly flexible, blade-like strips.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses very easily, yielding the same dense sublimate as antimony. The odor of sulphur dioxide may also be noticed. On charcoal, with soda, yields sulphur test. In closed tube fuses easily, yields a little sulphur and a dark sublimate which is brownish red when cold.

Soluble completely in strong boiling hydrochloric acid, with evolution of  $\text{H}_2\text{S}$ , with precipitation of white basic salt on addition of water and after dilution an orange precipitate on addition of  $\text{H}_2\text{S}$ . Strong nitric acid decomposes stibnite into white  $\text{Sb}_2\text{O}_3$  and S. Strong hot solution of KOH colors stibnite yellow and partially dissolves it. From the solution hydrochloric acid will throw down an orange precipitate.

**SIMILAR SPECIES.**—Differs from galenite in cleavage, and from all sulphides by ease of fusion and cloud-like fumes.

**REMARKS.**—Occurs as described p. 333, in narrow veins and as irregular replacements in limestone and in beds of disputed origin. The most important localities are Hunan, China, and the central plateau of France. Others are Querátero, Mexico; Iyo and Sujo, Japan; Borneo; Pereta, Tuscany. In this country it was mined in Arkansas and is obtained from Alaska and California.

#### KERMESITE.—Red Antimony.

**COMPOSITION.**— $\text{Sb}_2\text{S}_3\text{O}$  or  $2\text{Sb}_2\text{S}_3\cdot\text{Sb}_2\text{O}_3$ , (Sb 75.0, S 20.0, O 5.0 per cent.).

**GENERAL DESCRIPTION.**—Fine hair-like tufts of radiating fibers and needle-like crystals, of a deep cherry-red color and almost metallic lustre.

**PHYSICAL CHARACTERS.**—Nearly opaque. Lustre, adamantine. Color, dark cherry red. Streak, brownish red. H., 1 to 1.5. Sp. gr., 4.5 to 4.6. Sectile and in thin leaves slightly flexible.

**BEFORE BLOWPIPE, ETC.**—As for stibnite.

**REMARKS.**—Kermesite results from partial oxidation of stibnite. Extensive deposits exist at Pereta, Tuscany.

#### VALENTINITE.

**COMPOSITION.**— $\text{Sb}_2\text{O}_3$ , (Sb, 83.3 per cent.).

**GENERAL DESCRIPTION.**—Small white flat crystals (orthorhombic) or radiating groups of silky lustre and white or gray color. Also in spheroidal masses with radiated lamellar structure.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, adamantine or silky. Color, white, gray, pale red. Streak, white. H., 2.5 to 3. Sp. gr., 5.57.

**BEFORE BLOWPIPE, ETC.**—Fuses easily, coating the charcoal with white oxide. In R. F. is reduced, but again oxidizes and coats the coal, coloring the flame green. Soluble in hydrochloric acid.

**REMARKS.**—Occurs in quantity in radiated form at Ain Bebbouch, Algiers; and massive at Kostainik, Servia. In other localities as Rosia, Tuscany; Braunsdorf, Saxony, in crystals.

#### SENARMONTITE.

**COMPOSITION.**— $\text{Sb}_2\text{O}_3$ , (Sb, 83.3 per cent.).

**GENERAL DESCRIPTION.**—Colorless to gray octahedral crystals and granular masses.

**PHYSICAL CHARACTERS.**—Transparent to translucent. Lustre, resinous, <sup>almost adamantine</sup> Color, colorless or gray. Streak, white. H., 2 to 2.5. Sp. gr., 5.22 to 5.30.

**BEFORE BLOWPIPE, ETC.**—Like valentinite.

**REMARKS.**—Occurs as large replacement deposit in clay and limestone at Djebel-Hamimat, Algeria. Elsewhere chiefly as small crystals on other antimony minerals as at Kostainik, Servia, and Wolfe Co., Quebec.

#### ANTIMONY OCHRE.

##### Cervantite and Stibiconite.

**COMPOSITION.**—Cervantite,  $\text{Sb}_2\text{O}_3$ , Stibiconite,  $\text{Sb}_2\text{O}_3$ ,  $\text{H}_2\text{O}$ .

**GENERAL DESCRIPTION.**—Pale yellow to reddish white, masses, crusts and powder with greasy lustre or dull. Streak white. H., 4 to 5.5. Sp. gr., 4.08 to 5.28.

**BEFORE BLOWPIPE, ETC.**—Infusible in forceps. *Stibiconite* yields water in closed tube, decrepitates and fuses on charcoal. *Cervantite* yields no water, and on charcoal is easily reduced.

**REMARKS.**—These species are the common result of the oxidation of antimony deposits and usually occur together as in Borneo. The extensive deposits in Sonora, Mexico and the upper 60 feet of the Pricov, Bohemia, deposit are called *stibiconite* while others as at Pereta, Tuscany, are called *cervantite*.

### THE VANADIUM MINERALS.

The minerals described are:

|                  |                                    |                       |              |
|------------------|------------------------------------|-----------------------|--------------|
| <i>Sulphide</i>  | <i>Patronite</i>                   | $VS_4(?)$             |              |
| <i>Vanadates</i> | <i>Vanadinite</i>                  | $Pb_3Cl(VO_4)_3$      | Hexagonal    |
|                  | <i>Descloisite</i>                 | $(PbZn)_2(OH)VO_4$    | Orthorhombic |
|                  | <i>Hewettite and Metahewettite</i> | $CaO, 3V_2O_5, 9H_2O$ |              |
| <i>Silicates</i> | <i>Roscoelite</i>                  | Vanadium Mica         |              |

Other minerals containing vanadium are carnotite, and the briefly described and in part indefinite species mottramite, psittacinite, dechenite, volborthite, pucherite, and pascoite.

### ECONOMIC IMPORTANCE.

It was proved\* in 1830 that the unusual ductility of the iron made from the Taberg, Sweden, ores was due to the vanadium in the ores. Since that the use of vanadium in iron and steel has slowly increased.

Iron castings are made by vanadium finer grained and less porous.

It removes oxygen and nitrogen from steel and the combined effect of this and a small amount (0.15 to 0.25 per cent.) retained in the steel enormously increases the tensile strength and thereby the resistance to shock and abrasion. Vanadium steel is increasingly used for steel castings for locomotives, automobiles, die blocks, heavy drop forge work, etc.

Tough alloys are made with copper, such as vanadium bronze much used for trolley wheels, bronze gearing, etc.

The oxide  $V_2O_5$  is used in place of platinum as a catalytic agent in the manufacture of sulphuric acid and other processes and with aniline as a black dye and in making an indelible ink.

This country produced in 1914 *carnotite* and *roscoelite* ore containing 452 tons of vanadium.† The great source, however, is the

\* *Mining World*, 1905, p. 659.

† Mineral Resources U. S. 1914, p. 14.

*patronite* of Peru, which is oxidized and reduced either with Thermit or in the electric furnace to form ferro-vanadium.

Roscoelite is roasted with salt, the sodium vanadate extracted with water, ferrous sulphate added and the precipitated iron vanadate reduced in the electric furnace. The product is a ferro-vanadium containing 25 to 50 per cent. of vanadium. The process for vanadinite, now of relatively little importance, involved previous extraction of the lead by reduction with carbon and sodium carbonate, the slag being treated as above.

In the production of radium from carnotite, the vanadium remains in solution as sodium vanadate from which it is precipitated by ferrous sulphate.

#### THE FORMATION AND OCCURRENCE OF VANADIUM DEPOSITS.

Vanadium is not a rare element, it occurs in small amounts in many igneous rocks as  $V_2O_5$  up to .03-.05 per cent. replacing  $Fe_2O_3$  and  $Al_2O_3$  in some pyroxenes (up to 2 per cent.) amphiboles and micas and is almost invariably present in magmatic deposits of titaniferous iron.\* (5 analyses average 0.27 per cent.) Notably the ore of Taberg, Sweden.

#### Sediments.

After weathering of the igneous rocks the vanadium is concentrated in the resulting clays, sandstones (many of the copper-bearing sandstones carry vanadium) and beds of iron ore and economically important deposits have resulted as in the sandstones of Colorado and Utah, Cheshire, England, and Perm, Russia, and the oölitic limonites of Mafenay, France. It is found in the bauxites and clays near Paris.

The ash of lignites from San Rafael, Mendoza, Argentina and Yauli, Peru, contain about 38 per cent. of  $V_2O_5$ , and the asphalt grahamite of West Virginia and Oklahoma carries vanadium; the great deposit of vanadium sulphide in Cerro de Pasco is in large part an asphalt containing a large amount of sulphur.

#### Veins.

Vanadium also occurs in ore veins and ore bodies, notably with gold as the vanadium mica roscoelite as a primary mineral but more frequently as lead or copper vanadates in the oxidized portions.

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\* Clarke, Bull. 491, 673.

**PATRONITE.**

COMPOSITION.— $\text{VS}_4(?)$ , (58.79 S, 19.53 V, 1.87 Ni, 3.47 C, per cent.).

GENERAL DESCRIPTION.—Greenish black, resembling slaty coal, consisting of the vanadium sulphide mixed with metallic sulphides chiefly a nickel bearing pyrite (bravoite) and free sulphur. H. 3.5 and 2.5. Sp. gr. 2.5 and 2.71.

BEFORE BLOWPIPE, ETC.—No record has yet been made of its blowpipe, etc., characters. On roasting it yields the recorded test, p. 196, with hydrochloric acid.

REMARKS.\*—Found only as a lens-shaped mass 28 feet wide by 350 feet long, filling a fault in red shales (Cretaceous) at Minisraga, Cerro de Pasco, Peru. The larger portion of the mass (called quisquite H. 2.5, sp. gr., 1.75) is a lustrous black asphalt-like material with more sulphur than carbon which blends in a coke-like material 86 per cent. carbon (H. 4.5, sp. gr. 2.2). Below the lode is a blue black shale containing up to 13 per cent. vanadium oxide. The ore is burned and the ashes carrying the vanadium exported.

**VANADINITE.**

COMPOSITION.— $3\text{Pb}_3(\text{VO}_4)_2 \cdot \text{PbCl}_2$  or  $\text{Pb}_5\text{Cl}(\text{VO}_4)_3$ , (PbO, 78.7;  $\text{V}_2\text{O}_5$ , 19.4; Cl, 2.5 per cent.), often with P or As replacing V.

FIG. 378.

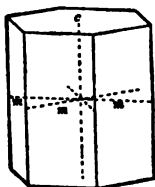
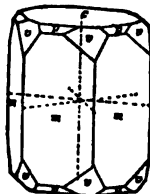


FIG. 379.



GENERAL DESCRIPTION.—Small, sharp, hexagonal prisms, sometimes hollow, of bright-red, yellow or brown color. Also parallel groups and globular masses of crystals.

CRYSTALLIZATION.—Hexagonal. Class third order pyramid, p. 57. Axis  $c = 0.712$ . Simple prism  $m$  with base  $c$ , or more rarely with pyramid  $p$  and third order pyramid  $v = (\frac{2}{3}a : 3a : a : 3c)$ ;  $\{2131\}$ , Fig. 379.

\* See *Jour. Am. Chem. Soc.*, 29, 1907, July, *Trans. Am. Inst. Min. Eng.*, 1909, 292. Bulletin 70, Bureau Mines, p. 55.

**Physical Characters.**—H., 3. Sp. gr., 6.66 to 7.23.

LUSTRE, resinous on fracture. OPAQUE, or translucent.

STREAK, white to pale yellow. TENACITY, brittle.

COLOR, deep red, bright red, yellow or brown.

**BEFORE BLOWPIPE, ETC.**—Fuses easily on charcoal to a black mass, yielding a yellow sublimate in the reducing flame. The residue gives deep-green bead, with salt of phosphorus in the reducing flame. With strong nitric acid the substance becomes deep red, then dissolves to a yellow solution. Fused with  $\text{KHSO}_4$ , yields a clear yellow, then a red, and finally yellow when cold.

**VARIETIES.**—*Endlichite*. The  $\text{V}_2\text{O}_5$  replaced in part by  $\text{As}_2\text{O}_5$ .

**REMARKS.**—Vanadinite occurs in the oxidized zone of lead-bearing veins in many localities especially New Mexico and Arizona. Sometimes the quantity is worth concentrating as at the Mammoth Gold Mine, Arizona, and Cutter, Sierra Co., N. M. Descloizite and wulfenite are common associates. Foreign localities are Dumfriesshire, Scotland, on calamine, Berezof Urals with pyromorphite.

The variety *endlichite* is reported\* in quantity in Baraga Co., Michigan, the ore showing 21.5 per cent. vanadium.

#### DESCLOIZITE.

**COMPOSITION.**— $(\text{Pb.Zn})(\text{PbOH})$ ,  $\text{VO}_4$ , ( $\text{PbO}$ , 55.4;  $\text{ZnO}$ , 19.7;  $\text{V}_2\text{O}_5$ , 22.7;  $\text{H}_2\text{O}$ , 2.2).

**GENERAL DESCRIPTION.**—Small purplish-red, brown or black crystals, forming a drusy surface of crust. Also fibrous, massive.

**PHYSICAL CHARACTERS.**—Transparent to nearly opaque. Luster, greasy. Color, purplish red, brown or black. Streak, orange or brown. H., 3.5. Sp. gr., 5.9 to 6.2.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses to black mass, enclosing metal. In closed tube yields water. Vanadium reactions as in vanadinite.

**VARIETIES.**—*Cuprodescloizite* in crusts and reniform masses with radiated structure contains 6.5 to 9 per cent. copper.

**REMARKS.**—Descloizite is a frequent associate of vanadinite and at the Mammoth Gold Mine, Arizona, and the Mimbres Mine near Georgetown, New Mexico, was more plentiful than the vanadinite. In Sierra de Cordoba, Argentina, occurs with pyromorphite and vanadinite.

The variety *cuprodescloizite* has been found in considerable quantities at Charcas, San Luis Potosí and Zacatecas, Mexico, and near Bisbee, Arizona; also in Otavi, German East Africa.

Less important vanadates are:

**MOTTRAMITE**  $(\text{CuPb})_2\text{V}_2\text{O}_{10} \cdot 2\text{H}_2\text{O}$ . Thin, blackish green incrustations upon the Keuper sandstone at Mottram, St. Andrews, Cheshire, England. Streak yellow,  $H = 3$ ,  $G = 5.9$ .

**PSITTACINITE.**— $4(\text{CuPb})\text{O} \cdot \text{V}_2\text{O}_5 \cdot \text{H}_2\text{O}$ , thin greenish incrustations on quartz in Silver Star District, Montana. Also Laurium, Greece.

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\* *Mineral Industry*, 1914, p. 762.



**DECHENITE.**— $\text{PbV}_2\text{O}_6$ . Massive botryoidal red to yellow. Streak orange yellow. H., 3 to 4. Sp. gr. 5.6 to 5.8 from Lauterthal, Prussia.

**VOLBORTHITE.**— $(\text{Cu.Ca.Ba})_3(\text{OH})_3\text{VO}_4$  in six-sided green to yellow tables. Streak yellowish green. From Urals and Utah.

**PUCHERITE.**— $\text{BiVO}_4$  in druses of small orthorhombic crystals of reddish brown color. Streak yellow. From Schneeberg, Saxony.

#### HEWETTITE AND METAHEWETTITE.

**COMPOSITION.**— $\text{CaO} \cdot 3\text{V}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$ . ( $\text{V}_2\text{O}_5$  70.01,  $\text{V}_2\text{O}_3$  0.35,  $\text{CaO}$  7.25,  $\text{H}_2\text{O}$  21.30 per cent.).

**GENERAL DESCRIPTION.**—Both occur as reddish earthy powders from mahogany red to brownish red the hewettite being the brighter. Hewettite also occurs in mahogany red needles and metahewettite in aggregates of highly pleochroic scales. Sp. gr., 2.554; hewettite, 2.511 metahewettite.

**BEFORE BLOWPIPE, ETC.**—Both darken on heating and as water escapes again grow lighter in color ending bronze (hewettite) or yellow brown (metahewettite). Melt easily to a dark red liquid. Both slightly soluble in water and yield the described test, p. 196, with hydrochloric acid.

**REMARKS.**—Hewettite occurs in pockets and fissures of a shale overlying patronite. Metahewettite is the chief constituent of a red vanadium ore from Paradox Valley, Montrose Co., Colorado, and through a wide area to Thompson, Utah. Occurs as an impregnation of sandstone. At Thompson it is associated with a gray vanadium-bearing silicate and with particles of selenium.

**PASCOITE** is  $2\text{CaO} \cdot 3\text{V}_2\text{O}_5 \cdot 11\text{H}_2\text{O}$  in orange red thin plates (monoclinic) somewhat adamantine lustre. An alteration of patronite not observed in the surface deposit at Minisruga but has formed since on the walls of an exploratory tunnel.

#### ROSCOELITE.—Vanadium Mica.

**COMPOSITION.**—Doubtful,  $\text{V}_2\text{O}_3$  replacing  $\text{Al}_2\text{O}_3$  in muscovite formula perhaps. Percentage of  $\text{V}_2\text{O}_3$  very variable, sometimes 20–29 per cent.

**GENERAL DESCRIPTION.**—Minute scales with micaceous cleavage dark green to brown in color suggesting a chlorite. Lustre pearly. H., 2. Sp. gr., 2.92 to 2.94.

**BEFORE BLOWPIPE, ETC.**—Fuses easily to a black glass. Essentially insoluble in acids. Gives emerald green bead in R. F. with salt of phosphorus after fusion with sodium carbonate gives the described test, p. 196, with hydrochloric acid.

**Remarks.**—Occurs as primary mineral in gold veins in Granite Creek, California, and with gold telluride at the Magnolia District, Colorado. Near Newmire and Placerville, on both sides of Bear creek in San Miguel Co., Colorado, as an impregnation of a fine-grained sandstone showing as a dull green band nearly parallel to the bedding. Although averaging only  $1\frac{1}{2}$  per cent.  $\text{V}_2\text{O}_5$  is mined at a profit.

## THE URANIUM AND RADIUM MINERALS.

The minerals described are:

|                   |                   |  |              |
|-------------------|-------------------|--|--------------|
| <i>Uranate</i>    | <b>Uraninite</b>  | Uranyl uranate $2\text{UO}_3 \cdot \text{UO}_3(?)$   | Isometric    |
| <i>Vanadate</i>   | <b>Carnotite</b>  | $(\text{K}_2\text{Ca})_2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 3\text{H}_2\text{O}(?)$ |              |
| <i>Phosphates</i> | <i>Autunite</i>   | $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$                          | Orthorhombic |
|                   | <i>Torbernite</i> | $\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$                          | Tetragonal   |

Coracite, and gummite and uraconite are mentioned briefly after uraninite, uvanite after carnotite. Uranium is also present in the described species thorianite, thorite, fergusonite, samarskite, euxenite, polycrase, and xenotime, and in a large series\* of phosphates, carbonates, arsenates, sulphates and silicates.

## ECONOMIC IMPORTANCE.

The metal uranium has a limited use in uranium steel, as a small percentage of uranium increases the elasticity and hardness of ordinary steel.

A few tons of sodium uranate, commercially known as uranium yellow, are used each year in coloring glass yellow with a greenish reflex, and in coloring porcelain orange or black. A small amount is used in photography and in the manufacture of uranium salts important in the laboratory.

Aside from this the importance of uranium lies in its use for the extraction of radium which is always with uranium in amount proportionate to the uranium present.

The ratio is constant for old, unaltered minerals and has been calculated as:

$$\frac{\text{Ra}}{\text{U}} = 3.4 \times 10^{-7}.$$

That is, from 1 gm. U there would develop .00000034 gm. radium (or 1 gm. Ra from 3,000,000 gm. U), thereafter there would be equilibrium.

If, however, the mineral is relatively young and secondary or if it has been altered by percolating waters and one or more of products removed *equilibrium may not exist and the ratio be different.*

Many tons of uraninite have been worked over to obtain a few grams of impure radium chloride, the remarkable properties of which are being widely studied. It

\* See Bulletin 70, Bureau of Mines, p. 92. Some of species are sulphate, johannite, arsenate, trögerite, silicate uranophane, phosphate fritzscheite, carbonate, liebigite.

seems probable that there is here the first known instance of the decomposition of the chemical atom, for radium gives off helium apparently as a decomposition product, and with the evolution of an amount of energy far beyond any previous conception. It also is continually throwing off emanations or rays which affect a photographic plate and discharge an electroscope. Some of these too are of a material character. Still years must elapse before any loss of weight can be detected by the most delicate balance.

The uses of radium are in scientific research and in medicine, though in the latter the results are still uncertain. Good results are claimed in treatment of lupus, skin diseases, and some forms of cancer and it is said to have favorable results on rheumatism.

Baths have been established by the Austrian government at St. Joachimsthal which are recommended for rheumatism, neuralgia, chronic eczema, etc.

Radium has been proved in a number of cases to change the color of minerals such as diamond and sapphire.

The three minerals which are important commercial sources of uranium and radium are carnotite, uraninite and autunite, and smaller amounts may be credited to uvanite and torbernite.

The production\* in 1914 in the United States was 4,294 tons of ore, carrying 87.2 tons of  $U_3O_8$  and 22.3 grams of metallic radium, chiefly from carnotite from Colorado and Utah but some from *uvanite* from the Henry Mountains, Utah.

Other sources were uraninite from Cornwall, Austria and the mines of Colorado, of carnotite from Olary, Australia, and of autunite from Guarda, Portugal.

Uraninite is roasted with sodium carbonate and nitrate, leached with water and the residues treated with sulphuric and nitric acids, giving uranyl sulphate, from which other salts are made.

Ores containing both uranium and vanadium (carnotite, uvanite) are usually subjected to wet treatment, boiled with a solution of sodium or potassium carbonate or treated with dilute sulphuric acids. At other times it is roasted with salt or fused with acid potassium sulphate and leached with water.

The uranium salts are in the solution and are suitably precipitated, the radium† is in the residues from which it and barium are obtained together and separated by fractional crystallization based on the difference in solubility of their chlorides.

#### FORMATION AND OCCURRENCE OF URANIUM DEPOSITS.

Uranium is found in granitic rocks and their pegmatites usually with tungsten, in small amounts chiefly as crystalline uraninite.

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\* Mineral Resources U. S. 1914, p. 14.

† See Bull. 70, Bureau of Mines, 69 to 82.

**Veins.**

Important deposits are generally in veins, the primary mineral being usually the amorphous variety of uraninite pitchblende.

*In Tin Veins.*—In Cornwall and Devon in several veins, especially one at Grampound.\*

*In Silver Nickel Cobalt Veins.*—In the Erzgebirge, especially at Joachimsthal, Bohemia, near but not with tin, in slates near granite.

*In Silver Gold Veins.*—In Gilpin Co., Col. (Wood mine, Kirk mine, etc.), in gneiss and mica schist with silver- and gold-bearing pyrite and chalcopyrite.

**Sedimentary.**

Uranium minerals, especially carnotite, occur concentrated in the Dakota sandstone in Utah and Colorado. In Utah, where it has in part replaced the original calcite cement, at other times appears in fissures or funnel-shaped cavities. Fossil remains are frequent and the carnotite is abundant in and near them.

**URANINITE.—Pitchblende.**

**COMPOSITION.**—Uranyl uranate and may contain Ca, N, Th, Zr, Fe, Cu, Bi, etc.

**GENERAL DESCRIPTION.**—A black massive mineral of botryoidal or granular structure and pitch-like appearance. Rarely in small isometric crystals.

**Physical Characters.** H., 5.5. Sp. gr., 6.5 to 9.7.

LUSTRE, pitch-like, submetallic.

OPAQUE.

STREAK, gray, olive green, dark brown.

TENACITY, brittle.

COLOR, some shade of black.

**BEFORE BLOWPIPE, ETC.**—Infusible or very slightly fused on edges, sometimes coloring the flame green from copper. On charcoal with soda may yield reaction for lead, arsenic and sulphur. In borax yields a green bead made enamel black by flaming. Soluble in nitric acid to a yellow liquid from which ammonia throws down a bright yellow precipitate. See also p. 195.

**SIMILAR SPECIES.**—The appearance and streak are frequently sufficient distinctions. The bead tests are characteristic.

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\* Beyschlag, Vogt & Krusch (Truscott), p. 713.

**VARIETIES.**—*Crystallized.* The crystals of the granites and their pegmatites are complex in composition and often carry rare earths and nitrogen, because of which other names have been given such as *cleveite*, *nivenite*, *bröggerite*, *uranniobite*.

*Pitchblende.*—The uraninite of the ore veins appears to be of colloidal origin; it contains no rare earths and little nitrogen, but contains water and is often intermixed with metallic sulphides.

*Coracite.*—Partially altered uraninite.

**REMARKS.**—The important variety *pitchblende* occurs in veins as stated p. 343, another important deposit being the Vereinigt Mine at Johanngeorgenstadt, Saxony. *Coracite* occurs north of Sault Ste. Marie.

The crystallized variety occurs in pegmatites as at Branchville, Conn., Anneröd, Norway, Mitchell and Yancy Cos., North Carolina. Nodular material occurs in a pegmatite at Abraki Pahai, India.

**GUMMITE.**—An alteration of uraninite of doubtful composition but with 61–75 per cent. of  $\text{UO}_3$  occurs in rounded and flattened gum-like masses of reddish yellow to red or brownish color. H., 2.5, sp. gr., 4. Principal locality, the Flat Rock Mine, Mitchell Co., N. C., but also Texas, and Joachimsthal, Bohemia.

### CARNOTITE.

**COMPOSITION.**— $(\text{K}_2, \text{Ca})\text{O}, 2\text{UO}_3, \text{V}_2\text{O}_5 + \text{H}_2\text{O}$ . (?) It is proposed to use the name carnotite for the potassium compound and tyuyamunite for the calcium compound.

**GENERAL DESCRIPTION.**—Usually a canary yellow or lemon yellow material, but sometimes red or black. Sometimes in loosely cohering masses of minute scales, oftener disseminated, filling interstices in sandstone. Rarely compact and wax-like.

**CRYSTALLIZATION.**—Under the microscope shows rhombic plates with basal cleavage and rhombic symmetry.

**BEFORE BLOWPIPE, ETC.**—Easily soluble in hydrochloric or nitric acid.

**REMARKS.**—Occurs as stated p. 343, in sandstone in Colorado and Utah, notably in Paradox Valley, Colorado, and San Juan Co., Utah.

The Utah deposits carry less carnotite and the ore varies more in color than the deposits of Colorado. Further east, as at Placerville, the carnotite is small in amount and the dominant species is roscoelite.

Carnotite in small amounts is found in crevices in a granite at Olary, South Australia, and a large deposit is reported under the name ferghanite at Ferghana, Russian Turkestan.

**UVANITE,**  $2\text{UO}_3, 3\text{V}_2\text{O}_5, 15\text{H}_2\text{O}$  is a recently described brownish-yellow hydrous uranium vanadate resembling carnotite in appearance and occurring in economic quantities at Temple Rock, Emery Co., Utah.

**AUTUNITE.—Lime Uranite.**

COMPOSITION.— $\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 + 8\text{H}_2\text{O}$ , ( $\text{UO}_2$  63.7,  $\text{CaO}$  6.1,  $\text{P}_2\text{O}_5$  15.5,  $\text{H}_2\text{O}$  15.7 per cent.).

GENERAL DESCRIPTION.—Nearly square ( $90^\circ 43'$ ) orthorhombic plates of bright yellow color and pearly lustre, or in micaceous aggregates.

PHYSICAL CHARACTERS.—Translucent. Lustre, pearly on base. Color, lemon to sulphur yellow. Streak, pale yellow. H., 2 to 2.5. Sp. gr., 3.05 to 3.19. Brittle. Cleavage basal.

BEFORE BLOWPIPE, ETC.—On charcoal fuses with intumescence to a black crystalline globule. With salt of phosphorus or borax in the reducing flame yields a green bead. Dissolves in nitric acid to a yellow solution.

REMARKS.—The only deposit of economic importance is in northern Portugal. The veins are in granite and schist and are richest near Guarda in Beira. The vein material is largely quartz and feldspar with clay and the autunite is disseminated. Torbernite is present and in the vicinity are veins carrying tungsten, tin, galena, etc. Occurs in many localities in small amounts.

**TORBERNITE.—Copper Uranite.**

COMPOSITION.— $\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 + 8\text{H}_2\text{O}$ , ( $\text{UO}_2$  61.2,  $\text{CuO}$  8.4,  $\text{P}_2\text{O}_5$  15.1,  $\text{H}_2\text{O}$  15.3 per cent.).

GENERAL DESCRIPTION.—Thin square tetragonal plates of bright green color and pearly lustre. Sometimes in pyramids or micaceous aggregates.

PHYSICAL CHARACTERS.—Translucent. Lustre, pearly. Color, emerald to grass green. Streak, pale green. H., 2 to 2.5. Sp. gr., 3.4 to 3.6. Brittle.

BEFORE BLOWPIPE, ETC.—Fuses easily to a black mass and colors the flame green. In borax yields a green glass in O. F., which becomes opaque red in R. F. Soluble in nitric acid to a yellowish-green solution.

REMARKS.—The deposit of autunite at and near Guarda, Portugal, contains torbernite and a deposit reported near Farina, South Australia, is principally torbernite. Other localities are Cornwall, England, and Joachimsthal, Bohemia.

**THE CHROMIUM MINERALS.**

The minerals described are:

|          |                           |            |
|----------|---------------------------|------------|
| Chromite | $\text{FeCr}_2\text{O}_4$ | Isometric  |
| Crocoite | $\text{PbCrO}_4$          | Monoclinic |

Spinel, chrysolite, serpentine, pyroxene, mica, garnet, chlorite, etc., have chromium-bearing varieties, and there are chromium-bearing clays\* and a few unimportant chromates.†

**ECONOMIC IMPORTANCE.**

The only commercial ore is chromite. This country produced in 1915‡ 3,281 long tons, chiefly from Shasta and Fresno counties,

‡ Mineral Resources, U. S., 1915, pt. 1, p. 2.

\* Wolchonskoite, miloschite, chrome ochre.

† Phoenicochroite, vauquelinite, tarapacaité.

California. In the same period this country imported 76,455 tons as follows:

|                       | Exported to U. S. | Total Output |
|-----------------------|-------------------|--------------|
| New Caledonia.....    | 28,031            | 67,000       |
| Rhodesia.....         | 22,800            | 57,333       |
| Portugese Africa..... | 11,230            |              |
| Canada.....           | 10,087            |              |
| Greece.....           | 4,305             |              |

Turkey, Russ'a, Japan and India are also producers.

The most important use is the manufacture of sodium and potassium bichromate and chromate, used in calico printing, electric batteries, the chrome colors and pigments, etc. Chromite is also used in the manufacture of ferrochrome, which in turn is used in making chrome steel, much used for high speed tools, armor plate and projectiles which possesses great hardness and resistance to impact.

Mixed with a suitable binder chromite is made into highly refractory bricks for copper and steel furnaces.

Ferrochrome is made in the electric furnace.

#### FORMATION AND OCCURRENCE OF CHROMIUM DEPOSITS.

The only ore of chromium is chromite and all known deposits of chromite occur in peridotite or the serpentine derived from it,\* almost entirely as magmatic segregations, occasionally as secondary chromite by alteration of chromium-bearing silicates.

#### Magmatic Segregations.

The earth's crust contains, it is estimated, .01 per cent. of chromium but the peridotites contain generally 0.2 to 0.5 per cent. and up to 1 per cent.† of  $\text{Cr}_2\text{O}_3$  and the segregations up to 60 per cent. chiefly as chromite but also as chrome spinel (picotite) and the chromium-bearing silicates mentioned on last page.

The deposits may be in essentially unaltered peridotite as at the Island of Hestnandö, Norway; Mt. Dun, New Zealand, or Kraubat, Styria; or they may be in serpentine rock as at Feragen, Norway, Tirbaghi Hills and Mt. Dere, New Caledonia; Thetford, Canada; Selukwe and Beira, Rhodesia.

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\* Beyschlag, Vogt & Krusch (Truscott), p. 244.

† Beyschlag, Vogt und Krusch (Truscott), p. 244.

### Secondary Deposits.

Secondary deposits of chromite due to the decomposition of chrome-bearing silicates are reported in Bosnia.

### Residual Deposits.

Chromite being very resistant to atmospheric influences is very common in gravels, these forming part of the New Caledonia deposits and at one time utilized from the Ural platinum deposits.

### CHROMITE.—Chromic Iron.

COMPOSITION.— $\text{FeCr}_2\text{O}_4$ , (FeO 32,  $\text{Cr}_2\text{O}_3$  68 per cent.), sometimes with  $\text{Al}_2\text{O}_3$  or MgO as replacing elements.

GENERAL DESCRIPTION.—Usually a massive black mineral resembling magnetite. Occurs either granular or compact or as disseminated grains. Rarely in small octahedral crystals. Frequently with more or less serpentine, mechanically intermixed, giving rise to green and yellow spots and streaks.

Physical Characters. H., 5.5. Sp. gr., 4.3 to 4.6.

LUSTRE, sub-metallic to metallic.

OPAQUE.

STREAK, dark-brown.

TENACITY, brittle.

COLOR, black.

May be slightly magnetic.

BEFORE BLOWPIPE, ETC.—Infusible, sometimes slightly fused by reducing flame, and *then* becomes magnetic. In salt of phosphorus, in oxidizing flame, gives yellow color hot, but on cooling becomes a fine emerald-green. With soda and nitre on platinum fuses to a mass, which is chrome-yellow when cold. Insoluble in acids.

SIMILAR SPECIES.—Chromite is distinguished from other black minerals by the salt of phosphorus reactions, and to a considerable extent by the serpentine with which it occurs.

REMARKS.—Occurs as described, p. 346. In this country the Woods Mine, near Baltimore, furnished from 1828 to 1850 most of the ore used by the world, the rest coming from the platinum deposits of the Urals. Later deposits were worked in Lancaster County, Pa., and in California and the latter are still worked.

### CROCOITE.

COMPOSITION.— $\text{PbCrO}_4$ , (PbO, 68.9;  $\text{CrO}_3$ , 31.1 per cent.).

GENERAL DESCRIPTION.—Bright hyacinth-red mineral, usually in monoclinic prismatic crystals, but also granular and columnar. The color is like that of potassium dichromate.



**PHYSICAL CHARACTERS.**—Translucent. Lustre, adamantine. Color, hyacinth red. Streak, orange yellow. H., 2.5 to 3. Sp. gr., 5.9 to 6.1. Sectile. Cleavage, prismatic.

**BEFORE BLOWPIPE, ETC.**—In closed tube, decrepitates violently, becomes dark, but recovers color on cooling. Fuses very easily, and is reduced to metallic lead with deflagration, the coal being coated with a yellow sublimate. With borax or S.Ph., forms yellow glasses, which are bright green when cold. Soluble in nitric acid to a yellow solution. Fused with  $\text{KHSO}_4$  in closed tube, yields a dark-violet mass, red on solidifying and greenish-white when cold, which distinguishes it from vanadinite.

**REMARKS.**—Chromium was discovered in samples of this mineral by Vauquelin in 1797. It occurs in lead-bearing veins in gneiss and granite in Berezof, Mursinska and Nischni Tagilsk, Urals. Similarly in Hungary and Brazil. Fine crystals come from the Broken Hill Mine, Australia. It is nowhere found in commercial quantities.

### THE MOLYBDENUM MINERALS.

The minerals described are:

|                 |                    |                  |              |
|-----------------|--------------------|------------------|--------------|
| <i>Sulphide</i> | <b>Molybdenite</b> | $\text{MoS}_2$   | Hexagonal    |
| <i>Oxide</i>    | <i>Molybdite</i>   | $\text{MoO}_3$   | Orthorhombic |
|                 | Wulfenite          | $\text{PbMoO}_4$ | Tetragonal   |

Other molybdates\* are powellite,  $\text{CaMoO}_4$ , pateraite,  $\text{CoMoO}_4$ , and belonesite,  $\text{MgMoO}_4$ .

### ECONOMIC IMPORTANCE.

The only ores are molybdenite and, in one or two instances, wulfenite. The production is chiefly from Queensland and New South Wales, Australia, South Norway and Canada. The production probably is not over 300 tons per year.† None was produced in this country in 1914–1915, though work was commenced on a deposit near Georgetown, Colo. In general, the ore is less than 3 per cent. and is concentrated by flotation.

An alloy with iron or manganese containing 50 to 75 per cent. Mo, is prepared by the aluminothermic process or by heating the molybdenite in a carbon tube with the electric arc, and is used to toughen and harden steel for wire drawing, tool steel, crank and shaft forgings, etc. Alloys with nickel and chromium are also made.

The metal is used in various electrical devices.

A considerable quantity is used in the production of molybdenum salts, such as

*Ammonium molybdate*, used to determine phosphorus in iron

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\* Silicates are unknown.

† Australia, 1913, 145 tons.

and in Europe as a fireproofing material and as a disinfectant. *Sodium molybdate*, used to impart a blue color to pottery and in dyeing silks and woollens, and *molybdic acid* from which useful chemical reagents are prepared.

The great demand from France in 1914 is said to be due to a process for the preservation of cordite.\*

#### FORMATION AND OCCURRENCE OF MOLYBDENUM DEPOSITS.

Molybdenum occurs in igneous, metamorphic and sedimentary rocks, principally as the sulphide molybdenite.

The economically important deposits appear to be always connected with granites and frequently associated with tungsten.

**Disseminated**—or following joints and crevices as at Cooper, Maine.

**In pegmatites**—as at Romaine, Quebec.

**In veins in granite**—as at Knaben Mine, S. Norway; Chelan county, Washington; and Dillon, Montana.

**Contacts**.—Sometimes in contacts of granite with limestone, as at Texada Island, B. C., where the molybdenite is fine-grained and massive and included in ore bodies of bornite and chalcopyrite.

#### MOLYBDENITE.

**COMPOSITION**.— $\text{MoS}_2$ , (Mo 60.0, S 40.0 per cent.).

**GENERAL DESCRIPTION**.—Thin graphite-like scales or foliated masses of metallic lustre and bluish gray color, easily separated into flexible non-elastic scales. Sometimes in tabular hexagonal forms and fine granular masses. Soft, unctuous and marks paper.

**Physical Characters**. H., 1 to 1.5. Sp. gr., 4.6 to 4.9.

LUSTRE, metallic.

OPAQUE.

STREAK, greenish.\*

TENACITY, sectile to malleable.

COLOR, bluish lead gray.

CLEAVAGE, basal.

**BEFORE BLOWPIPE, ETC.**—In forceps infusible, but at high heat colors the flame yellowish green. On charcoal gives sulphurous odor and slight sublimate, yellow hot, white cold, and deep blue when flashed with the reducing flame. Soluble in strong nitric acid and during solution on platinum it is luminous. With sul-

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\* *Mineral Industry*, 1914, p. 529.

phuric acid yields a blue solution. In salt of phosphorous and borax yields characteristic molybdenum reactions.

**SIMILAR SPECIES.**—Differs from graphite in streak and blowpipe reactions. May usually be distinguished by its lighter bluish gray color.

**REMARKS.**—Economic deposits are as stated, p. 349. Commercially unimportant occurrences are in the tin mines of Bohemia, Saxony, Cornwall and elsewhere and the minute flakes common in California gold quartz and the copper veins of Clifton, Arizona, and Chili. It is found in many American localities, especially, Westmoreland, N. H., Blue Hill Bay, Maine, Okanogan Co., Wash., and Pitkin, Colorado.

#### MOLYBDITE.

**COMPOSITION.**— $\text{MoO}_3$ , (Mo 66.7 per cent.).†

**GENERAL DESCRIPTION.**—An earthy yellow powder or, rarely tufts and hair-like crystals of yellowish-white color.

**PHYSICAL CHARACTERS.**—Opaque to translucent. Lustre, dull or silky. Color, yellow or yellowish white. Streak, straw yellow. H., 1 to 2. Sp. gr., 4.49 to 4.5.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses, yielding crystals yellow hot, white cold, and made deep blue by the reducing flame. In borax and salt of phosphorus gives characteristic molybdenum reactions.

#### WULFENITE.

**COMPOSITION.**— $\text{PbMoO}_4$ , sometimes containing Ca, Cr. V.

**GENERAL DESCRIPTION.**—Usually in thin, square, tetragonal crystals of yellow, orange or bright orange-red color and resinous lustre. Less frequently in granular masses or acute pyramidal crystals. H., 3. Sp. gr., 6.7–7.

**BEFORE BLOWPIPE, ETC.**—Fuses easily on charcoal, giving yellow coat and finally a metallic globule.

Tests with sulphuric acid, borax and salt of phosphorus as described, p. 190.

**REMARKS.**—Wulfenite occurs with other lead minerals. It is found in many localities in New Mexico and Arizona;‡ in the lead regions of Wisconsin and Arizona; at Phoenixville, Pa.; Inyo County, Cal.; Southampton, Mass., and many other places, always associated with other ores of lead.

#### THE TUNGSTEN MINERALS.

The minerals described are:

|            |                            |            |
|------------|----------------------------|------------|
| Wolframite | $(\text{FeMn})\text{WO}_4$ | Monoclinic |
| Scheelite  | $\text{CaWO}_4$            | Tetragonal |

\* Best seen on glazed porcelain.

† According to Schaller it is molybdate of iron. *Zeit. f. Kryst.*, 43. 331.

‡ Commercial quantities have been obtained from the Mammoth Mine, Pinal Co.

Minor species are tungstite, meymacite, cuprotungstite, cuproscheelite and stolzite.

#### ECONOMIC IMPORTANCE.

The world's total production is about 10,000 tons per year of 60 per cent.  $WO_3$ . In 1915 the United States produced 2,165 tons chiefly from Colorado and California. The great producers in 1913 were:\*

|                     |       |                 |     |
|---------------------|-------|-----------------|-----|
| Burma .....         | 1,732 | Australia ..... | 752 |
| United States ..... | 1,397 | Bolivia .....   | 564 |
| Portugal .....      | 1,380 | Argentina ..... | 539 |

The material is often recovered as a by-product from tin, as at Heberton, Queensland, or in the treatment of gold or silver ores (British Columbia) or with copper ores (Peru) and usually undergoes preliminary concentration (to 60 per cent.  $WO_3$ ).

Tungstic oxide,  $WO_3$ , may first be extracted from the ore and then reduced to tungsten in the powder form.

In this country the ore is reduced directly in the electric furnace to ferro-tungsten, which, added to steel, gives a product of great toughness, especially valued for high-speed cutting tools, which retain their temper even when red hot and are said to save 20 to 30 per cent. in power alone. The steel is also used for armor plate and projectiles and for permanent magnets. Alloys with Pt, Cr, Co, Al, etc., are made, the tungsten usually giving strength to the alloy.

Metallic tungsten is used in place of platinum for winding resistance furnaces and in electrical contacts and as a filament in incandescent lamps. Its melting point is  $3267^{\circ}C$ .

Tungstic acid and sodium tungstate are used in dyeing and to render cotton and wood unflammable. Other uses are in pigments.

#### THE FORMATION AND OCCURRENCE OF TUNGSTEN DEPOSITS.

##### Veins.

The only important ores are wolframite and scheelite, these occur chiefly in veins in or near granite either with cassiterite or of the cassiterite type, but also in veins with silver, gold, etc.

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\* *Mineral Industry*, 1914, p. 756.

*Veins with Cassiterite.*—Wolframite is the most constant associate of cassiterite and secondary scheelite is frequent. Examples are:

Tavoy District, Lower Burma; tungstite said also to occur. Sierra de Estrella, Portugal; with much arsenopyrite. Heberton, Queensland; Cornwall; Zinnwald and Altenberg.

*Veins without Cassiterite.*—

*Wolframite* occurs at Sierra de Cordoba, Argentina (carries Columbium); Castello Branco, and Beira, Portugal; Boulder county, Colorado, near silver and gold veins. In some of the Queensland and Chilean veins it is intimately associated with bismuth or silver.

*Scheelite* often occurs in gold veins as in Atolia, Kern county, California; Halifax county, Nova Scotia; in veins in slate with gold-bearing arsenopyrite, and Sloan District, British Columbia, in large lenses. Large deposits exist at Scheelite, Nevada.

#### Replacements.

The deposits at Trumbull, Conn., are regarded as replacements\* of limestone; the scheelite preceded the wolframite, the latter occurring only as pseudomorphs after scheelite. The deposits near Lead and Deadwood, South Dakota, are in dolomite.

#### WOLFRAMITE, Ferberite, Huebnerite.

COMPOSITION.— $(\text{Fe.Mn})\text{WO}_4$ . (About 76 per cent.  $\text{WO}_3$ .) Strictly  $\text{FeWO}_4$  is ferberite,  $\text{MnWO}_4$  is huebnerite. The species, however, replace each other.†

GENERAL DESCRIPTION.—Heavy dark-gray to black sub-metallic crystals, orthorhombic in appearance, bladed non-terminated crystals often reddish brown in color, cleavable and granular masses.

CRYSTALLIZATION.—Monoclinic. Axes  $a : b : c = 0.830 : 1 : 0.868$ ,  $\beta = 89^\circ 22'$ .

Usual combination shown in Fig. 378 of unit prism *m*, ortho

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\* Beck and Weed, p. 539.

† F. L. Hess proposes the arbitrary distinction into *ferberite* for iron tungstate with less than 20 per cent. manganese tungstate, *huebnerite* for manganese tungstate with less than 20 per cent. iron tungstate and *wolframite* for all intermediate proportions.

pinacoid  $a$ , unit clino dome  $d$  and  $+$  and  $-$  ortho domes  $e = (a : \infty b : \frac{1}{2}c)$ ;  $\{102\}$  Supplement angles,  $mm = 79^\circ 23'$ ;  $dd = 81^\circ 54'$ ;  $ae = 61^\circ 54'$ ;  $ae = 62^\circ 54'$ .

**Physical Characters.**—H., 5 to 5.5. Sp. gr., 6.8 to 7.55.

LUSTRE, resinous to sub-metallic.

STREAK, dark-brown, yellowish-brown and gray.

COLOR, dark-gray, black, and reddish-brown.

OPAQUE to translucent. In one locality transparent.

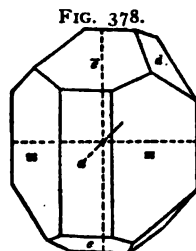
CLEAVAGE very perfect in one direction,  $\{010\}$ .

BEFORE BLOWPIPE, ETC.—Fuses readily to a crystalline globule, which is magnetic. In salt of phosphorus yields a reddish-yellow glass, which in reducing flame becomes green, and if this bead is pulverized and dissolved with tin, in dilute hydrochloric acid, a blue solution results.

Partially soluble in hydrochloric acid, the solution becoming blue on addition of tin.

**SIMILAR SPECIES.**—Distinguished by its fusibility and specific gravity from similar iron and manganese minerals.

**REMARKS.**—The chief occurrences are as stated, p. 352, and other similar deposits in Angaras, Peru; Siam; Salamanca, Spain; St. Leonards, France; Brazil and elsewhere. Found also in many deposits of stream tin, sometimes in considerable quantities. Occurs in at least twelve of the United States, but is worked chiefly in Colorado, and to a minor extent in Idaho, Nevada, New Mexico and South Dakota.



Zinnwald.

### SCHEELITE.

**COMPOSITION.**— $\text{CaWO}_4$ , (CaO 19.4,  $\text{WO}_3$  80.6 per cent.), sometimes with replacement by molybdenum.

**GENERAL DESCRIPTION.**—Heavy brownish white or white masses and square pyramids. Also drusy crusts of yellow or brown crystals.

**CRYSTALLIZATION.**—Tetragonal. Class of third order pyramid, p. 47. Axis  $c = 1.536$ .

The unit first order pyramid  $p$  and second order  $d$  are most common with sometimes a modifying third order pyramid,  $x = (a : 3a : 3c)$ ,  $\{311\}$ . Supplement angles are  $pp = 79^\circ 55'$ ;  $ee = 72^\circ 40'$ .

FIG. 379.

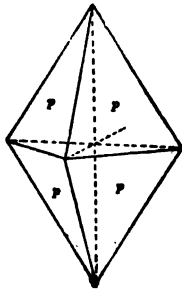
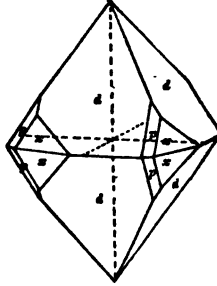
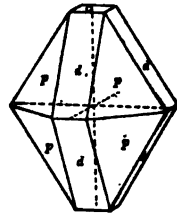


FIG. 380.



Schlackenwald.

FIG. 381.



Trumbull, Conn.

**Physical Characters.** H., 4.5 to 5. Sp. gr., 5.4 to 6.1.

LUSTRE, adamantine.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, pale yellow, gray, brown, white or green.

CLEAVAGE, distinct parallel to first order pyramid, indistinct parallel to second order pyramid.

BEFORE BLOWPIPE, ETC.—Fusible with difficulty on sharp edges. In salt of phosphorus forms a clear bead which in the reducing flame becomes deep blue, and if the bead is powdered and dissolved in dilute hydrochloric acid it yields a deep blue solution, especially on addition of metallic tin. Scheelite is soluble in hydrochloric or nitric acid, leaving a yellow residue.

SIMILAR SPECIES.—Distinguished among non-metallic minerals by its weight and behavior in salt of phosphorus.

REMARKS.—The chief occurrences are as stated, p. 352; it is also frequent as a secondary mineral with wolframite. There are many minor occurrences with gold or silver or lead and copper deposits. Examples are with gold at Warren's, Idaho, and Val Toppa, Piedmont, with silver and lead at Oracle, Arizona, and Snake River, Nevada; with copper at Llamuco, Chile.

## THE COLUMBIUM AND TANTALUM MINERALS.

The minerals described are:

|                            |  |              |
|----------------------------|--|--------------|
| Columbite }<br>Tantalite } | $(\text{Fe.Mn})(\text{Cb.Ta})_2\text{O}_6$                             | Orthorhombic |
| Samarskite                 | $(\text{Fe.Ca.UO}_2)_2(\text{Y.Er.Ce})_2(\text{Cb.Ta})_4\text{O}_{21}$ | Orthorhombic |
| Fergusonite                | $(\text{Y Er.Ce})(\text{Cb.Ta})\text{O}_4$                             | Tetragonal   |

Less common are yttrotantalite, pyrochlore, euxenite, skogbolite, stibiotantalite.

The wolframites of Rosario, Argentina; and Auvergne, France, contain columbium.

#### ECONOMIC IMPORTANCE.

No production is reported for this country, the small amount used, possibly 100 tons, coming from Western Australia. Colum-  
bium has practically no uses, tantalum, on account of its hardness,  
toughness, ductility and high fusion point ( $2,250^{\circ}$  to  $2,300^{\circ}$  C.)  
is made\* into filaments for incandescent lights which are con-  
siderably used.

It is used in dental and surgical steel, watch springs, etc., and  
is suggested for laboratory crucibles.

#### FORMATION AND OCCURRENCE OF COLUMBIUM AND TANTALUM DEPOSITS.

These elements are usually found together and the minerals  
which they form are found almost entirely in granite pegmatites,  
as at the Etta Mine, South Dakota, or in the gravels resulting  
from the decomposition of pegmatites as at Greenbushes, West  
Australia, in pebbles 5-6 inches in diameter.†

#### COLUMBITE.—TANTALITE.

COMPOSITION.— $(\text{Fe, Mn})(\text{Cb, Ta})_2\text{O}_6$  (grading from columbite,  
 $\text{FeCb}_2\text{O}_6$ , to tantalite,  $\text{FeTa}_2\text{O}_6$ ). Usually contains a little tin,  
often a little tungsten.

GENERAL DESCRIPTION.—Black, often bright and sometimes  
iridescent crystals. Also in large dull black masses and in pebbles  
in tin gravels.

CRYSTALLIZATION.—Orthorhombic.  $a : b : c = .828 : 1 : .889$ .  
Common forms  $a \{010\}$ ,  $b \{100\}$ ,  $m = \{110\}$ ,  $d \{730\}$ . Supple-  
ment angle  $mm = 79^{\circ} 17'$ .

Physical Characters.—H., 6. Sp. gr. 5.4 to 7.

LUSTRE, sub-metallic.

OPAQUE.

STREAK, dark red to black.

TENACITY, brittle.

COLOR, black.

CLEAVAGE in two directions at right angles.

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\* By pressing a mixture of the oxide and paraffine into threads, then reducing  
them to metal in a vacuum. It is said one pound of tantalum will make 20,000  
20-candle power filaments.

† Also small, dull pebbles of stibiotantalite,  $\text{Sb}(\text{CbTa})_2\text{O}_6$ .



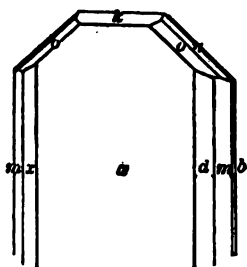
**BEFORE BLOWPIPE, ETC.**—Infusible. Fused with potassium hydroxide and boiled with tin gives deep-blue solution on dilution with water the color disappears. Insoluble in hydrochloric acid, partially decomposed by sulphuric acid.

**SIMILAR SPECIES.**—By infusibility and lower specific gravity from wolframite, by greater opacity and absence of tin test from cassiterite.

**REMARKS.**—Occurs in considerable quantities in large black crystals at the Etta Mine, Black Hills, South Dakota, and as pebbles 5-6 inches in diameter in the tin gravels of Greenbushes, Western Australia.

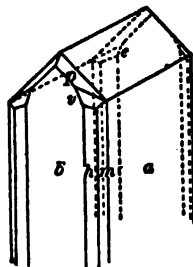
Famous crystal localities are the cryolite of Greenland, the granites of Bodenmais, Bavaria; Miask, Urals; Haddam, Connecticut and Amelia Co., Virginia. It is found in the gold sands of Sanarka Urals.

FIG. 382.



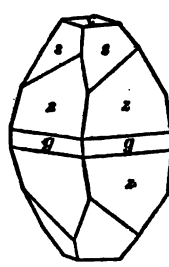
Columbite.

FIG. 383.



Samarskite.

FIG. 384.



Fergusonite.

#### SAMARSKITE.

**COMPOSITION.**— $R_2R_3(Cb, Ta)_2O_6$ .  $R$  chiefly FeCaUO<sub>2</sub>.  $R$  Ce, Yt metals.

**GENERAL DESCRIPTION.**—Irregularly shaped masses and rough orthorhombic crystals (Fig. 383) of velvet black color and notable lustre. Streak reddish brown. H., 5 to 6. Sp. gr., 5.6 to 5.8.

**BEFORE BLOWPIPE, ETC.**—Fuses with difficulty to black glass; in closed tube glows, cracks and blackens. With salt of phosphorus green uranium bead. Decomposed sufficiently by boiling concentrated sulphuric acid to give a blue color on addition of zinc or tin and hydrochloric acid.

**REMARKS.**—Found in granite pegmatites at Mitchell and McDowell counties, North Carolina, and near Miask, Urals, in both cases with columbite. Also in Queensland, Australia.

#### FERGUSONITE.

**COMPOSITION.**— $(Y, Er, Ce)(CbTa)_2O_4$ .

**GENERAL DESCRIPTION.**—Brownish black, tetragonal crystals (Fig. 384) and masses with brilliant glassy lustre on fresh fracture. Streak pale brown. H., 5.5 to 6. Sp. gr., 5.8 or less if hydrated.

**BEFORE BLOWPIPE, ETC.**—Infusible, becomes pale yellow on charcoal. Decomposed by sulphuric acid, the white residue giving a blue color with tin and hydrochloric acid.

REMARKS.—Occurs in considerable quantity in the granite of Baringer Hill, Llano Co., Texas. Other localities are Cape Farewell, Greenland; Ytterby, Sweden; Arendal, Norway.

### THE COPPER MINERALS.

The minerals described are:

|                         |                     |   |              |
|-------------------------|---------------------|---|--------------|
| <i>Metal</i>            | <b>Copper</b>       | Cu  | Isometric    |
| <i>Sulphides</i>        | <b>Covellite</b>    | CuS   | Hexagonal    |
|                         | <b>Chalcocite</b>   | Cu <sub>2</sub> S   | Orthorhombic |
| <i>Sulphoarsenite</i>   | <b>Bornite</b>      | Cu <sub>3</sub> FeS <sub>4</sub>                                  | Isometric    |
|                         | <b>Chalcopyrite</b> | CuFeS <sub>2</sub>  | Tetragonal   |
|                         | <b>Enargite</b>     | Cu <sub>3</sub> AsS <sub>4</sub>                                  | Orthorhombic |
|                         | <b>Famatinite</b>   | Cu <sub>3</sub> SbS <sub>4</sub>                                  |              |
| <i>Sulphoantimonite</i> | <b>Tetrahedrite</b> | Cu <sub>3</sub> Sb <sub>2</sub> S <sub>7</sub>                    | Isometric    |
| <i>Oxides</i>           | <b>Cuprite</b>      | Cu <sub>2</sub> O   | Isometric    |
|                         | <b>Tenorite</b>     | CuO   | Triclinic    |
| <i>Basic chloride</i>   | <b>Atacamite</b>    | Cu(OH)Cl.Cu(OH) <sub>2</sub>                                      | Orthorhombic |
| <i>Sulphates</i>        | <b>Chalcantite</b>  | CuSO <sub>4</sub> .5H <sub>2</sub> O                              | Triclinic    |
|                         | <b>Brochantite</b>  | Cu <sub>4</sub> SO <sub>4</sub> (OH) <sub>6</sub>                 | Orthorhombic |
| <i>Carbonates</i>       | <b>Malachite</b>    | Cu <sub>2</sub> (OH) <sub>2</sub> CO <sub>3</sub>                 | Monoclinic   |
|                         | <b>Azurite</b>      | Cu <sub>3</sub> (OH) <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub> | Monoclinic   |
| <i>Silicates</i>        | <b>Chrysocolla</b>  | CuSiO <sub>3</sub> .2H <sub>2</sub> O                             |              |

The great deposits of pyrite and pyrrhotite usually carry copper and both directly because of its extraction and indirectly as the primary ores from which the richer ores largely form are the greatest and most important sources.

### ECONOMIC IMPORTANCE.

The world's production of copper in 1915 was 1,061,283 metric tons, of which this country produced 646,212; Bolivia, 75,000; Canada 47,202; Peru, 47,142; and Mexico, Australia, Germany, Africa, Spain and Portugal from 25,000 to 35,000 each.

The ores which yielded this product probably do not differ greatly in proportions from an earlier estimate,† based on the production of 1909.

|                    |                    |
|--------------------|--------------------|
| Sulphide ores..... | 60 to 65 per cent. |
| Oxidized ores..... | 15 to 20 "         |
| Native copper..... | 12 "               |
| Enargite.....      | 5 "                |
| Tetrahedrite.....  | 1/2 "              |

The production in this country was derived approximately in the following percentages: Arizona, 31; Montana, 18.5; Michigan,

\* *Engineering and Mining Journal*, 1916, p. 48.

† Bayschlag, Vogt & Krusch (Truscott), 872.

17; Utah, 13; New Mexico, 4.5; Nevada, 4; Alaska, 4; the remaining 8 per cent. chiefly from California, Idaho and Tennessee.

The method of extraction of the copper is dependent upon the nature of the ore, and may roughly be classed under three headings:

Treatment of native copper.

Treatment of oxidized ores.

Treatment of sulphides.

A great many processes exist or have existed, but these for a general brief discussion may be reduced to a small number of type processes of which the others are variations due to local conditions or constituents of the ore.

#### **Treatment of Native Copper.**

Native copper occurs in enormous quantities in Michigan, and the deposits mined average less than two per cent. of copper, although occasionally large masses of the metal are found. The rock is crushed by steam stamps and the copper separated from the rock by the action of water and the use of jigs, tables, and other concentrating apparatus. The concentrated material is then melted in a large reverberatory furnace with limestone and slags from previous operations. The new slag thus formed contains the remaining rock and is removed, leaving behind copper, which after a period of reduction by charcoal and stirring is cast into ingots.

#### **Treatment of Oxidized Ores.**

The oxidized ores in Arizona which averaged over ten per cent. of copper, were smelted in blast-furnaces with coke and the necessary flux to make a slag with the associated gangue. The result being an impure metal called black copper, which was later refined. The ores are now more often mixed with sulphides.

The carbonate and silicate ores at Ajo,† Arizona, carrying 1.5 per cent. copper, are being leached with dilute sulphuric acid and electrolytically precipitated.

#### **Treatment of Sulphides.**

The treatment of sulphides is quite varied, depending chiefly on the presence or absence of arsenic, the richness of the ore and the local conditions.

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\* *Engineering and Mining Journal*, 1916, p. 48.

† *Ibid.*, p. 55.

The modern practice involves a concentration by flotation which may bring a 2 per cent. ore up to 25 per cent., but makes necessary, on account of the pulverized condition, either a roasting or smelting in a reverberatory furnace or sintering and then smelting in a blast furnace.\*

The ores always contain iron, copper and sulphur, and may contain arsenic, antimony, silver, gold, etc. All the smelting processes depend on the facts that at high temperatures copper has a greater affinity for sulphur than iron has, and iron a stronger affinity than copper for oxygen. So that if such an ore is subjected to oxidation by roasting, oxides result; but in the subsequent fusion, if enough sulphur has been left, the copper will form a fusible sulphide, and the oxidized iron will unite with the gangue and the flux to form a slag.

By regulating the roasting, the sulphur contents may be brought to any desired percentage.

The roasted ore is smelted for copper either in a shaft-furnace, or when silver or gold is present, in a reverberatory furnace. The blast furnaces are rectangular in cross section and may be as large as 25 ft. x 144 ft. and may treat over 3,000 tons per day.

The slag and matte flow through a trapped spout to an outer fore hearth where the matte settles and is tapped and the slag flows out at the top.

The copper matte is often blown in a converter, by which the sulphur, arsenic and antimony are driven off, the iron oxidized and converted into slag, and black copper obtained.

The crude copper is refined either by remelting and oxidation, or more frequently electrolytically.

The great uses of copper are in electrical work and in alloys with zinc and tin, such as brass, yellow metal, bronze, bell metal, and German silver. Copper sulphate is also important.

#### THE FORMATION AND OCCURRENCE OF COPPER ORES.

Copper is obtained from deposits of all the great classes and it is estimated† that the world's yield is about in the following proportions:

|  |                    |
|--|--------------------|
| Magmatic segregation.....                      | 10 to 11 per cent. |
| Contacts and contacts combined with veins..... | 25 to 30 "         |
| Veins.....                                     | 40 "               |
| Metasomatic replacements.....                  | 3 "                |
| Native copper.....                             | 12 "               |
| Ore beds.....                                  | 4 "                |
| By-products.....                               | 1 "                |

\* Lawrence Addicks in *Eng. and Min. Journ.*, 1916, p. 91.

† Beyschlag, Vogt & Krusch (Truscott), p. 944.

**Magmatic Segregations.**

The chalcopyrite in norite at Sudbury, the sulphides in serpentine at Mt. Catini, Tuscany, and the bornite at O'kiep Namaqualand, Cape Colony, in a rock chiefly feldspar, are generally accepted as segregations.

Many bedded copper deposits formerly attributed to heated waters are probably magmatic intrusions such as the great copper-bearing pyrite deposits of Rio Tinto, Spain, and Mt. Lyell, Tasmania.\*

**Contacts Usually with Veins.**

True contacts with garnet, augite, wernerite, wollastonite, vesuvianite, etc., are often associated with ordinary copper veins.

The great deposits of this type are: Clifton, Bisbee, and Globe, Arizona; Mednorudiansk, Urals; Bingham Cañon, Utah; and Cananea, Mexico.

**Veins.**

This most productive class includes the great deposits of chalcocite, bornite and enargite at Butte, Montana, in granite near rhyolite; Burra Burra, S. Australia, of carbonates and oxides, in a complex of slate, limestone and sandstone; Moonta and Wallaroo, S. Australia, of chalcopyrite and bornite in quartz porphyry but with the carbonates and *atacamite* in large quantities; Aschio, Japan. Sometimes the presence of tourmaline or cassiterite indicate high temperatures and coöperation of vapors as at Cactus Mine, Utah; Las Condes, Chili; Dolceath Mine, Cornwall; Heberton, Australia.

**Metasomatic Replacements.**

The great auriferous pyrite deposits of Rio Tinto and Mt. Lyell mentioned under magmatic segregations are by some regarded as replacements.†

The copper-bearing pyrrhotite and pyrite of Ducktown, Tenn., are said to have been formed by replacement of limestone by "igneous emanations."‡

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\* Ibid., 943 and 877.

† Lindgren, p. 602, 605.

‡ Ibid., p. 709.

Other replacements are the important deposits of Bosccheggrano, Tuscany, and Otavi, German S. W. Africa.\*

**Sedimentary.**

Occurrence in beds in sedimentary rocks does not prove sedimentary origin.

Throughout Europe and America sandstones are found which contain copper ores, chiefly chalcocite, but of date later than the sediments and probably deposited from solutions of pre-existing ore in the sediments or adjoining rocks. Such deposits occur at Coro Coro, Bolivia; Colorado and New Mexico; the Permian sandstones of Russia, and elsewhere.

At Boleo, Lower California, conglomerates and tuffs interstratified with copper minerals occur, the tuffs being regarded as intrusions of volcanic mud and the concentration of the copper minerals to the action of springs. Nodules of malachite and azurite occur in the Bunter sandstone in many localities,† some of which are worked, as in Lorraine; Rhenish Prussia; Mottram, St. Andrews, England; etc.

Copper is sometimes found in placers and river beds as at Ste. Catalina, Argentina.

**Native Copper in Basic Lava Flows.**

The one great occurrence is in the melaphyre of the Lake Superior region, where the copper occurs with zeolites filling the blowholes of the melaphyre and also the interstices in a conglomerate, chiefly melaphyre.

True veins also occur, which are richest where they cross the melaphyre.

The intimate association with calcite and the zeolites laumontite, analcite, natrolite, etc., and such species as prehnite, epidote, datolite (carrying boron) and apophyllite (carrying fluorine) indicate deposition from water at moderate temperatures. It is a special case of *formation of zeolites* differing from the ordinary only in the presence of copper in the solutions.§

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\* Beyschlag, Vogt & Krusch (Truscott), 916.

† Ibid., 1182.

‡ Ibid., 1184.

§ These solutions are considered to be in part of magmatic origin and to have risen at the consolidation of the rocks. Beyschlag, Vogt & Krusch (Truscott), 935.

Many other relatively unimportant occurrences of native copper are associated with basic eruptive rocks with the same mineral association, calcite, prehnite, epidote and zeolites, such as the Faroe Islands; Oberstein, Germany; Bay of Fundy, N. S.

### **Oxidation and Cementation, or Secondary Enrichment of Copper Ores.**

In the upper portions of many copper deposits the primary ores, pyrite, pyrrhotite, chalcopyrite, etc., are oxidized. If much pyrite is present soluble sulphates,  $\text{CuSO}_4$  and  $\text{Fe}_2(\text{SO}_4)_3$  and insoluble ferric oxides and hydrates result\* and the copper is carried as copper sulphate by superficial waters to a lower level, sometimes leaving no copper at the outcrop as at Butte and Rio Tinto. The copper from these solutions is precipitated both by other sulphides and by organic matter as chalcocite or sometimes covellite or, if the primary ore is pyrite, partly as chalcopyrite, thus forming a zone of very much richer ore between the leached-out gossan and the unchanged primary ores at greater depths. Prominent examples of this are found at Rio Tinto, Spain; Butte, Montana; Ducktown, Tennessee; and Clifton, Arizona.

In other cases in which the primary ore is purer chalcopyrite or if carbonates in solution or as limestone neutralize the sulphuric acid, rich deposits of oxide ores form near the outcrop, especially malachite and azurite as in Arizona, Chessy, Mednorudiansk, Burra Burra, or of atacamite as in Chili and South Australia.

### **COPPER.—Native Copper.**

**COMPOSITION.**—Cu often containing Ag, sometimes Hg or Bi.

**GENERAL DESCRIPTION.**—A soft, *red*, malleable metal, with a

FIG. 385.

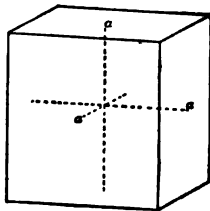


FIG. 386.

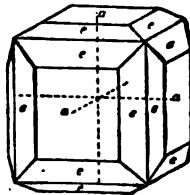
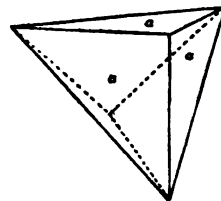


FIG. 387.



\* Beyschlag, Vogt & Krusch (Truscott), 881.

red streak. Usually in sheets or disseminated masses, varying from small grains to several hundred tons in weight. Also in threads and wire and in distorted crystals and twisted groups.

CRYSTALLIZATION.—Isometric. Tetrahexahedron and cube most frequent, Fig. 386, also twinned, Fig. 387, giving by elongation spear-shaped forms often complexly grouped and usually distorted.

**Physical Characters.** H., 2.5 to 3. Sp. gr., 8.8 to 8.9.

LUSTRE, metallic. OPAQUE.

STREAK, copper red. TENACITY, malleable and ductile.

COLOR, copper red, tarnishing nearly black.

BEFORE BLOWPIPE, ETC.—Fuses easily to a malleable globule, often coated with a black oxide. In beads, becomes in O. F. green when hot; blue, cold, and in R. F. opaque red. Soluble in nitric acid, with evolution of a brown gas, to a green solution, which will deposit copper on iron or steel. The solution becomes deep azure blue on addition of ammonia.

SIMILAR SPECIES.—Resembles niccolite and tarnished silver, differs in copper-red streak.

REMARKS.—Occurs in basic lava flows, as described p. 361, and to a limited extent in oxidation zone of other copper deposits as at the Coro Coro Mines in Bolivia; the Faroe Islands; Atacama, Chili; Wallaroo, South Australia, and elsewhere. In this country in addition to the Lake Superior deposits it has been found in twenty-seven states.

### COVELLITE.—Indigo Copper.

COMPOSITION.— $\text{Cu}_2\text{S}$  (Cu 66.44, S 33.56 per cent.).

GENERAL DESCRIPTION.—Very dark indigo blue submetallic masses often purplish when moistened. Rarely tabular hexagonal crystals. Streak shining gray to black. Somewhat flexible. H., 1.5 to 2. Sp. gr., 4.59 to 4.64.

BEFORE BLOWPIPE, ETC.—Burns with blue flame and odor of  $\text{SO}_2$ . In closed tube a sublimate of sulphur. Soluble in nitric acid and slowly soluble in hydrochloric acid.

REMARKS.—Probably always a cementation secondary enrichment mineral precipitated from copper sulphate solutions by older sulphides. Occurs in large masses at 1,100 feet level of mines at Butte, Montana. At the Rambler Mine, Wyoming, including the platinum mineral sperrylite. Foreign localities are Mansfeld, Thuringia; Boleo, Lower California; Chili. Found in various sandstones with chalcocite as at Cashin Mine, Colorado.



**CHALCOCITE.—Copper Glance.**

**COMPOSITION.**— $\text{Cu}_2\text{S}$ , (Cu 79.8, S 20.2 per cent.).

**GENERAL DESCRIPTION.**—Black granular or compact masses, with metallic lustre, or sometimes nodules or pseudomorphic after wood. Often coated with the green carbonate, malachite. Also in orthorhombic crystals.

**Physical Characters.** H., 2.5 to 3. Sp. gr., 5.5 to 5.8.

LUSTRE, metallic.

OPAQUE.

STREAK, lead gray:

TENACITY, brittle.

COLOR, blackish lead gray, with dull-black tarnish.

**BEFORE BLOWPIPE, Etc.**—Yields no sublimate in closed tube. On charcoal, with soda in R. F. yields a copper button and a strong sulphur reaction. If moistened with hydrochloric acid, colors the flame azure blue. In borax or salt of phosphorus, yields copper beads. Soluble in nitric acid, leaving a residue of sulphur.

**SIMILAR SPECIES.**—It is more brittle than argentite, and differs from bornite in not becoming magnetic on fusion.

**REMARKS.**—Often a cementation species but also primary, as in the deeper levels at Butte, Montana, and Virgilina, Va., and the 25 ft. veins at the Bonanza Mine, Copper River, Alaska.

In the numerous copper deposits in sandstone the principal mineral is chalcocite, often replacing wood and plants, as in Texas and New Mexico and the Permian beds of Russia.

Famous localities for crystallized chalcocite are Bristol, Conn., and Cornwall, England.

**BORNITE. — Purple Copper Ore. Horse Flesh Ore.**

**COMPOSITION.** —  $\text{Cu}_5\text{FeS}_4$ , (Cu 63.3, Fe 11.2, S 25.5 per cent.), but often contains admixed chalcocite.

**GENERAL DESCRIPTION.**—On fresh fracture, bornite is of a peculiar red-brown color and metallic lustre. It tarnishes to deep blue and purple tints, often variegated. Usually massive, sometimes small cubes or other isometric forms.

**Physical Characters.** H., 3. Sp. gr., 4.9 to 5.4.

LUSTRE, metallic.

OPAQUE.

STREAK, grayish black.

TENACITY, brittle.

COLOR, dark copper red, brownish or violet blue, often varied.

**BEFORE BLOWPIPE, ETC.**—Blackens, becomes red on cooling, and finally fuses to a brittle, magnetic globule and evolves sulphur

dioxide fumes. In oxidizing flame with borax or salt of phosphate phorus, gives green bead when hot, greenish blue when cold, the bead is opaque red in the reducing flame. Soluble in nitric acid, with separation of sulphur.

REMARKS.—Bornite is often found with chalcopyrite and is both primary and a cementation product, as at Mt. Lyell, Tasmania, and Butte, Montana. In certain localities it is the principal mineral, as at some Chilian mines and the magmatic segregations at O'kiep, Little Namaqualand, Cape Colony. It occurs also in commercial quantities with chalcocite but without chalcopyrite in quartz veins in an altered volcanic rock at Virgilina, Va., and as lenses in limestone with little chalcopyrite on Texada Island, British Columbia.

### CHALCOPYRITE.—Copper Pyrites. Yellow Copper Ore.

COMPOSITION.— $\text{CuFeS}_2$ , (Cu 34.5, Fe 30.5, S 35.0 per cent.), with mechanically intermixed pyrite at times.

GENERAL DESCRIPTION.—A bright brassy yellow mineral of metallic lustre, often with iridescent tarnish resembling that of bornite. Usually massive. Sometimes in crystals.

CRYSTALLIZATION.—Tetragonal. Scalenohedral class, p. 47. Axis  $l = 0.985$ .

Sphenoids predominate,  $p = \text{unit sphenoid}$ ;  $o = (a : a : \frac{1}{2}c)$ ;  $\{772\}$ ;  $t = (a : a : \frac{1}{4}c)$ ;  $\{114\}$ ;  $v = (a : a : 4c)$ ;  $\{441\}$ ;  $s = (a : 2a : c)$ ;  $\{212\}$ .

Supplement angles (over top)  $pp = 108^\circ 40'$ ;  $oo = 128^\circ 52'$ ;  $tt = 38^\circ 25'$ ;  $vv = 159^\circ 39'$ .

FIG. 388.

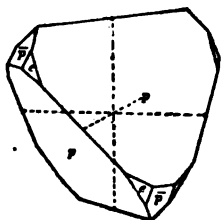


FIG. 389.

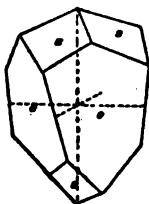
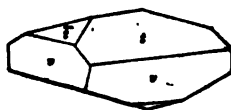


FIG. 390.



French Creek, Pa.

Ellenville, N. Y.

Physical Characters. H., 3.5 to 4. Sp. gr., 4.1 to 4.3.

LUSTRE, metallic.

OPAQUE.

STREAK, greenish black.

TENACITY, brittle.

COLOR, bright brass yellow, often tarnished in blue, purple and black hues.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses with scintillation to a brittle magnetic globule. With soda yields metallic malleable red button and sulphur test. In closed tube decrepitates, becomes dark and iridescent and may give deposit of sulphur. Flame and bead reaction like bornite. Soluble in nitric acid with separation of sulphur, and from the solution ammonia throws down a brown precipitate, and leaves the liquid deep blue in color.

**SIMILAR SPECIES.**—Chalcopyrite is softer and darker in color than pyrite, and differs from gold in black streak and brittleness.

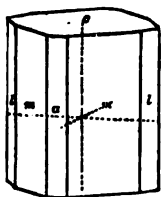
**REMARKS.**—Usually primary, often in small amount, cupriferous pyrite and pyrrhotite. Occurs also as cementation product, p. 362. Occurs in all classes of deposit, as described p. 360, in most of localities mentioned and in many others, being one of the great sulphides of metallic ore deposits.

### ENARGITE.

**COMPOSITION.**— $\text{Cu}_3\text{AsS}_4$  (Cu 48.3, As 19.1, S 32.6 per cent.). Sometimes with Cu replaced in part by Zn or Fe and As by Sb.

**GENERAL DESCRIPTION.**—A black brittle mineral of metallic lustre, occurring usually columnar or granular but sometimes in orthorhombic crystals.

FIG. 391.



**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.871 : 1 : 0.825$ .  $m$  = unit prism,  $l = (2a : b : \infty c)$ ;  $\{120\}$ . Supplement angles are  $mm = 82^\circ 7'$ ;  $ll = 120^\circ 7'$ .

Missoula Co., Mont. **Physical Characters.** H., 3. Sp. gr., 4.43 to 4.45.

LUSTRE, metallic.

OPAQUE.

STREAK, blackish gray.

TENACITY, brittle.

COLOR, black or blackish gray.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses, yields white fumes with garlic odor. With soda yields malleable copper and a reaction for sulphur. In closed tube decrepitates, yields sulphur sublimate, then fuses and yields red sublimate of arsenic sulphide. Soluble in nitric acid.

**REMARKS.**—As stated, p. 357, enargite is one of the great ores, yielding probably five per cent. of the copper of the world. It is apparently a primary mineral and forms nearly one third of the ore at Butte, Montana.\* Other large deposits are Sierra

\* Beyschlag, Vogt & Krusch (Truscott), p. 871.

Famatina, Argentina; in clay slate; Tinctic, Utah; with rich silver and gold minerals; Mancanyan, Luzon; with tetrahedrite in porphyry; Morococha and Cerro de Pasco, Peru, with tennantite; Hedworda Mine near Coquimbo, Chili, at Bor, Servia and Parad, Hungary, in porphyry.

**FAMATINITE.**— $\text{Cu}_3\text{SbS}_4$  (Cu 43.3; Sb 27.4; S 29.3, per cent.) is a mineral of metallic lustre and granular structure with a color suggesting that of fresh fractured bornite. Streak black. H., 3 to 4. Sp. gr., 4.5 to 4.6. Before the blowpipe it gives off white fumes of antimony and leaves a brittle black globule. It is found with enargite at Sierra Famatina, Argentina, and Cerro de Pasco, Peru, in considerable quantities. It is associated with the ores of Goldfield, Nevada.

### TETRAHEDRITE.—Gray Copper Ore.

**COMPOSITION.**— $\text{Cu}_8\text{Sb}_2\text{S}_{17}$ . Cu often partially replaced by Fe, Zn, Pb, Hg, Ag, and the Sb by As.

FIG. 392.

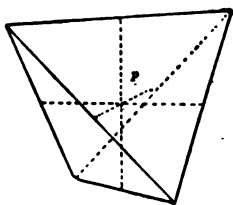


FIG. 393.

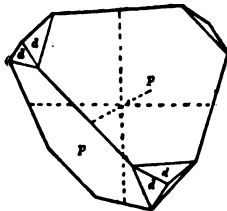
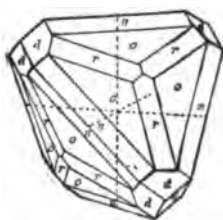


FIG. 394.



**GENERAL DESCRIPTION.**—A fine grained, dark gray mineral of metallic lustre. Characterized especially by the tetrahedral habit of its crystals which are sometimes coated with yellow chalcopryite.

FIG. 395.

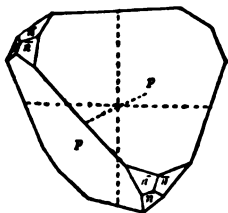
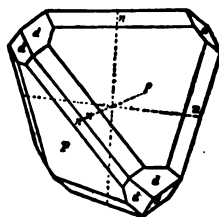


FIG. 396.



**CRYSTALLIZATION.**—Isometric. Hextetrahedral class, p. 62. The tetrahedron *p*, Fig. 392, usually predominates, often modified by the tristetrahedron  $n = (a : 2a : 2a); \{211\}$ ; Figs. 395, 396, and less frequently by other forms such as the dodecahedron *d*, Fig. 393, and the deltohedron  $r = (a : a : 2a); \{221\}$ ; Fig. 394.

**Physical Characters.** H., 3 to 4.5. Sp. gr., 4.5 to 5.1.

LUSTRE, metallic.

OPAQUE.

STREAK, black or reddish brown.

TENACITY, brittle.

COLOR, light steel to dark lead gray or iron black.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily to a globule which may be slightly magnetic. Evolves heavy white fumes with sometimes garlic odor. The roasted residue gives bead and flame reactions for copper. Soluble in nitric acid to a green solution with white residue.

**SIMILAR SPECIES.**—The crystals are characteristic. The fine grained fracture in conjunction with the color is often sufficient to distinguish it. It is softer than arsenopyrite and the metallic cobalt ores, and does not generally yield a strongly magnetic residue on heating. Bournonite and chalcocite are softer, and finally the blowpipe reactions are distinctive.

**VARIETIES.**—*Tennantite*—approximating  $\text{Cu}_3\text{As}_2\text{S}_7$ , but grading into ordinary tetrahedrite and undistinguishable by crystal form or general appearance.

*Freibergite*, argentiferous, and *schwartzite*, mercurial, are important ores respectively of silver and mercury. Other varieties carry bismuth, zinc or lead.

**REMARKS.**—Tetrahedrite is one of the most frequent minerals of the copper deposits, especially in veins in the schists and older eruptives. Widely distributed in the copper veins of the Andes, porphyries of Chili, the Peruvian Cordilleras and Algeria. Occurrences are numerous in Saxony, Harz, Hungary, France, Cornwall and elsewhere.

In this country abundant in the mines of Silverton and Aspen, Colorado, and at Park City, Utah. Also is found in the mines of Butte, Montana; and Bingham, Utah.

Tennantite occurs in crystals in Cornwall and massive in Mt. Lyell, Tasmania; Morococha, Peru; Teniente, Chile; Gilpin County, Colorado; Laramie County, Wyoming and sparingly in the enargite veins at Butte.

### **CUPRITE. — Red Oxide of Copper, Ruby Copper Ore.**

**COMPOSITION.** —  $\text{Cu}_2\text{O}$  (Cu 88.8 per cent.). Sometimes intermixed with limonite.

**GENERAL DESCRIPTION.**—Fine grained masses, dark red, brownish-red and earthy brick-red in color; or deep red to crimson, transparent, isometric crystals, usually octahedrons, or cubes. Also capillary.

FIG. 397.

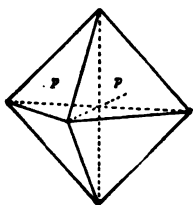


FIG. 398.

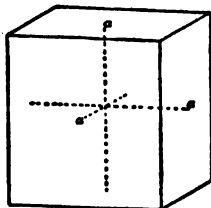
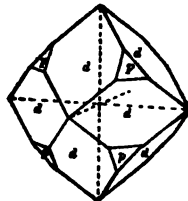


FIG. 399.



**CRYSTALLIZATION.**—Isometric. Class of gyroid, p. 66. The octahedron *p*, cube *a* and dodecahedron *d* predominating. Index of refraction for red light 2.849.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 5.85 to 6.15.

LUSTRE, adamantine or dull.

TRANSPARENT to opaque.

STREAK, brownish red.

TENACITY, brittle.

COLOR, crimson, scarlet, vermillion, or brownish red.

**BEFORE BLOWPIPE, ETC.**—On charcoal blackens and fuses easily to a malleable red button. Flame and bead tests give the color for copper. Soluble in nitric acid to a green solution. Soluble also in strong hydrochloric acid to a brown solution which diluted with water yields a white precipitate.

**SIMILAR SPECIES.**—It is softer than hematite and harder than cinnabar or proustite, and differs from them all by yielding an emerald-green flame and a malleable red metal on heating.

**REMARKS.**—Chiefly secondary, part in the gossan intermixed with limonite and in part developed lower as in limestones where copper solutions have formed carbonates. It has formed the principal or a very important portion of deposits at Cobar, New South Wales; Coro Coro, Bolivia; Chessy, France; Illapel, Chili; many mines in Peru; and Boleo, Lower California. In the United States it is especially abundant in the Bisbee district, Arizona; and an important ore in certain mines in Colorado, New Mexico, Nevada, Wyoming and California.

#### **TENORITE.—Melaconite, Black Oxide of Copper.**

**COMPOSITION.**—CuO, (Cu 79.85 per cent.).

**GENERAL DESCRIPTION.**—Dull black earthy masses, black powder and shining black scales.

**PHYSICAL CHARACTERS.**—Lustre, metallic in scales, dull in masses. Color and streak black. H., 3. Sp. gr., 5.82 to 6.25.

**BEFORE BLOWPIPE, ETC.**—Infusible, otherwise like cuprite.

**REMARKS.**—Occurs in fissures in the lava of Vesuvius, as a black coat on chalcopryrite and as dull black masses with chrysocolla.

**REMARKS.**—Occurs as a sublimation product at Vesuvius and as an occasional decomposition product in oxidized zone as at Bisbee, Arizona, and Bingham, Utah.

Said to occur in relatively large quantity at the Rambler Mine, Wyoming, and in Waldo district, Oregon, and to be intermixed with the secondary chalcocite of Ducktown, Tenn.

**BROCHANTITE.**— $\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$ . Velvety, emerald-green crusts of fine orthorhombic needle crystals, botryoidal masses and vein-like with fibrous structure. Transparent to translucent. Lustre, vitreous. Streak, pale green. H., 3.5 to 4. Sp. gr., 3.9.

**BEFORE BLOWPIPE, ETC.**—On charcoal turns black, colors the flame emerald green and leaves malleable red button. Insoluble in water, but soluble in acids. In closed tube yields water.

**REMARKS.**—A minor ore occurring occasionally in oxidized zone and sometimes in economic quantity, as at Chiquicamata, Chili; Monarch Mine, Chaffee Co., Colorado, and the Clifton-Morenci districts, Arizona, Coro Coro, Bolivia.

#### ATACAMITE.

**COMPOSITION.**— $\text{Cu}(\text{OH})\text{Cl} \cdot \text{Cu}(\text{OH})_2$ , (Cu 59.45, Cl 16.64 per cent.).

**GENERAL DESCRIPTION.**—Confused aggregates of crystals of bright or dark-green color. Also granular or compact massive, or as a crust. Rarely in slender orthorhombic prisms.

**PHYSICAL CHARACTERS.**—Translucent to transparent. Lustre, adamantine to vitreous. Color, bright green, emerald green, blackish green. Streak, apple green. H., 3 to 3.5. Sp. gr., 3.75 to 3.77.

**BEFORE BLOWPIPE, ETC.**—On charcoal yields white fumes and a coating which is brown near the assay and white at some distance from it, fuses to a copper-red, malleable button, and colors the flame a beautiful and persistent blue *without the aid of hydrochloric acid*. In closed tube yields water and a gray sublimate. Soluble in acids to a green solution.

**REMARKS.**—Found in large quantities in Chili in the oxidation zone at Atacama, partly as sand but also in veins, especially at Las Remolinos, Chili, and at Tocopilla, Bolivia, also very plentiful at Wallaroo, South Australia. Minor localities are Boleo, Lower California; Cornwall, England; Vesuvius and Etna.

#### CHALCANTHITE.—Blue Vitriol.

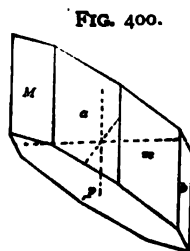
**COMPOSITION.**— $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , (CuO 31.8,  $\text{SO}_3$  32.1,  $\text{H}_2\text{O}$  36.1 per cent.).

**GENERAL DESCRIPTION.**—A blue, glassy mineral, with a disagreeable metallic taste. It occurs usually as an incrustation, with fibrous, stalactitic or botryoidal structure; but sometimes in flat triclinic crystals.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, vitreous. Color, deep blue to sky blue. Streak, white. H., 2.5. Sp. gr., 2.12 to 2.30. Brittle. Taste, metallic nauseous.

**CRYSTALLIZATION.**—Triclinic. Axes  $\bar{a} : \bar{b} : \bar{c} = 0.566 : 1 : 0.551$ . Axial angles  $\alpha = 82^\circ 21'$ ;  $\beta = 73^\circ 11'$ ;  $\gamma = 77^\circ 37'$ . Prominent forms, right and left unit prisms  $m$  and  $\bar{M}$ , unit pyramid  $p$ , and the pinacoids  $a$  and  $b$ . Angles  $m\bar{M} = 56^\circ 50'$ . Optically—.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses, coloring flame green and leaving metallic copper. In closed tube yields water and sulphur dioxide and leaves a white powder. Easily soluble in water to a blue solution.



**REMARKS.**—Chalcanthite is of great interest as the intermediate stage in the so-called secondary enrichment. Often present in the waters of copper mines, from which large quantities are recovered as at Rio Tinto, Spain, and at Wicklow, Ireland. Occasionally found in quantity and mined, as at Bluestone Mine, Lyon County, Nevada; United Verde Mine, Arizona; Copaquire, Taraposa and Chiquicamata, Chili.

**MALACHITE.**—Green Carbonate of Copper.

**COMPOSITION.**— $\text{Cu}_2(\text{OH})_2\text{CO}_3$ , (CuO 71.9, CO<sub>2</sub> 19.9, H<sub>2</sub>O 8.2 per cent.)

**GENERAL DESCRIPTION.**—Bright-green masses and crusts, often with a delicate, silky fibrous structure or banded in lighter and darker shades of green. Sometimes stalactitic. Also in dull-green, earthy masses, and rarely in small, slender, monoclinic crystals. Frequently coating other copper minerals or filling their crevices and seams.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 3.9 to 4.03.

LUSTRE, silky, adamantine or dull. TRANSLUCENT to opaque.

Streak, pale green.

TENACITY, brittle.

COLOR, bright emerald to grass green or nearly black.

**BEFORE BLOWPIPE, ETC.**—On charcoal, decrepitates, blackens, fuses, and colors the flame green, leaving a globule of metallic copper. In closed tube, blackens and yields water and carbon dioxide. Soluble in acids, with effervescence.

**SIMILAR SPECIES.**—Distinguished by color and effervescence with acids.

**REMARKS.**—Malachite is the most common oxidation product, and may occur in more important masses in the zone of enrichment by replacement of limestone or dolomite or as a later alteration of other secondary minerals such as chalcocite.

The purest and probably largest deposit is in limestone at Mednorudiansk near Nishni Tagilsk, which yields most of the malachite worked into art objects. Other famous localities are Bisbee and Morenci, Arizona; Santa Rita, New Mexico; Cobar, New South Wales; Bura Burra, Australia; many mines in Chili, and in the deposits in sandstone as at Coro Coro, Bolivia, and Perm, Russia. Often it occurs pseudomorphic after azurite and cuprite as at Chessy, France.

**AZURITE.**—Blue Carbonate of Copper.

**COMPOSITION.**— $\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$ , (CuO 69.2, CO<sub>2</sub> 25.6, H<sub>2</sub>O 5.2 per cent.).

**GENERAL DESCRIPTION.**—A dark-blue mineral occurring in highly modified, glassy, monoclinic crystals and groups. When

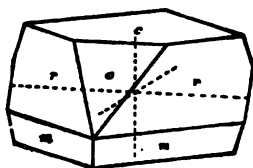


massive, it may be vitreous, velvety, or dull and earthy. It frequently occurs incrusting other copper ores, or distributed through their cracks and crevices.

CRYSTALLIZATION.—Monoclinic. Axes  $a : b : c = 0.850 : 1 : 0.881$ ;  $\beta = 87^\circ 36'$ .

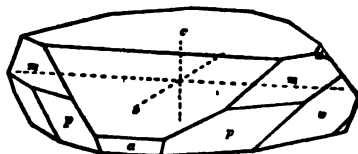
Crystals very varied in habit. Those figured show basal pina-

FIG. 401.



Arizona.

FIG. 402.



Chessy, France.

coid  $c$ , ortho-pinacoid  $a$ , unit prism  $m$ , unit dome  $o$ , and the pyramids  $p$ ,  $r$ , and  $v$ . Supplement angles are  $mm = 80^\circ 41'$ ;  $co = 44^\circ 46'$ . Optically +.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 3.77 to 3.83.

LUSTRE, vitreous.

TRANSLUCENT to opaque.

STREAK, blue.

TENACITY, brittle.

COLOR, dark blue to azure blue.

BEFORE BLOWPIPE, ETC.—As for malachite.

REMARKS.—The occurrences of azurite are essentially those of malachite. At Morenci, Arizona, and Laurium, Greece; the two species occur in concentric bands. Splendid crystals were found at Chessy, France, and Bisbee, Arizona.

### CHRYSOCOLLA.

COMPOSITION.— $\text{CuSiO}_3 + 2\text{H}_2\text{O}$ . Often very impure ( $\text{CuO}$  45.2,  $\text{SiO}_2$  34.3,  $\text{H}_2\text{O}$  20.5 per cent.).

GENERAL DESCRIPTION.—Green to blue incrustations and seams often opal-like in texture, or sometimes, from impurities, resembling a kaolin colored by copper. Also brown, resembling limonite, and in dull green earthy masses. Never found in crystals.

**Physical Characters.** H., 2 to 4. Sp. gr., 2 to 2.3.

LUSTRE, vitreous, dull.

TRANSLUCENT to opaque.

STREAK, white to pale blue.

TENACITY, brittle.

COLOR, green to light blue, brown when ferriferous.

**BEFORE BLOWPIPE. ETC.**—In forceps or on charcoal is infusible, but turns black, then brown and colors the flame emerald green. In bead, reacts for copper. With soda, yields malleable copper. In closed tube, yields water. Decomposed by hydrochloric acid, leaving a residue of silica. Boiled with KOH, yields a blue solution, from which excess of  $\text{NH}_4\text{Cl}$  precipitates flocculent  $\text{H}_2\text{SiO}_3$ .

**SIMILAR SPECIES.**—It is softer than turquoise or opal and does not effervesce like malachite.

**REMARKS.**—Chrysocola, while probably present in lavas and basalts, occurs principally in the oxidation zone. It is an important ore in Gila and Pinal Counties, Arizona; Hartville, Wyoming; Bullion District, Nevada; and occurs in most of the prominent copper-bearing regions.

### THE MERCURY OR QUICKSILVER MINERALS.

The minerals described are:

|                                 |                        |   |            |
|---------------------------------|------------------------|---|------------|
| <i>Metal</i>                    | <i>Mercury</i>         | Hg  |            |
| <i>Sulphides</i>                | <i>Cinnabar</i>        | HgS                                       | Hexagonal  |
|                                 | <i>Metacinnabarite</i> | HgS                                       | Isometric  |
|                                 | <i>Livingstonite</i>   | $\text{HgS} \cdot 4\text{Sb}_2\text{S}_3$ |            |
| <i>Selenides and Tellurides</i> | <i>Onofrite</i>        | $\text{HgS} \cdot \text{HgSe}$            |            |
|                                 | <i>Tiemannite</i>      | HgSe                                      | Isometric  |
|                                 | <i>Coloradoite</i>     | HgTe                                      |            |
| <i>Chlorides</i>                | <i>Calomel</i>         | $\text{Hg}_2\text{Cl}_2$                  | Tetragonal |
|                                 | <i>Terlinguaite</i>    | $\text{Hg}_2\text{ClO}$                   | Monoclinic |

Other species containing mercury are amalgam and mercurial tetrahedrite.\*

#### ECONOMIC IMPORTANCE.

The principal ore is cinnabar, though mercury is obtained from mercurial tetrahedrite, livingstonite, terlinguaite and metallic mercury.

The world's production† is between 4,000 and 5,000 short tons per year, of which in recent years Spain has furnished about one third and Italy, Austria and the United States each from one fifth to one sixth and a little has come from Mexico and other countries.

In 1915 this country produced‡ 775 tons, of which 522 came from California, the rest from Nevada and Texas.

In these deposits and in most others there is close association with the younger volcanic rocks. Almaden and Nikitovka belong

\* Mineral Resources U. S., 1914, p. 330.

† Engineering and Mining Journal, 1916, p. 67.

to an earlier period, but there are no essential genetic differences.\* In general, they have formed near the surface and cease with a few hundred feet of depth. The most constant associate is pyrite, sometimes marcasite; the other common sulphides are notably rare. The sulphides of antimony and arsenic are frequent and asphalt-like material occurs in several deposits.

Mercury is obtained from cinnabar by heating the larger lumps in a shaft-furnace, resembling a continuous lime kiln, with three exterior fire places. A little fuel is also mixed with the ore. The heat decomposes the sulphide, forming fumes of sulphur dioxide and mercury. These fumes are carried off through large iron pipes to condensers where the mercury is liquified. The finer ore is heated in a vertical shaft containing a series of inclined shelves down which the ore slips whenever any is drawn off at the bottom. The fumes go to the condensers already mentioned.

The principal uses of mercury are in making fulminates for explosive caps and it has a diminishing use in certain processes for the extraction of gold and silver from their ores and in the manufacture of vermilion. Minor uses are in barometers, thermometers and electrical appliances, antiseptics and in medicine.

#### FORMATION AND OCCURRENCE OF MERCURY DEPOSITS.

Mercury deposits are chiefly found filling the pores and cracks in quartzite, conglomerate or shattered limestone. At Sulphur Bank, Cal., and at Steamboat Springs, Nev., the formation is still proceeding and it is believed that the cinnabar is being precipitated from solution in hot waters containing excess of sodium sulphide before the emergence of the waters and as a result of the decomposition of the sodium sulphide. Similar depositions from hot sulphur springs have been observed in New Zealand and elsewhere.

*Almaden, Spain.*—The deposits, which are the richest and greatest yet discovered,§ consist of three porous beds—quartzites, separated by barren clay slates (dipping vertically and formerly

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\* Beyschlag, Vogt & Krusch (Truscott), pp. 182, 461.

† Ibid., 458.

‡ Beyschlag, Vogt & Krusch (Truscott), 182, 461

§ Said to average 8 per cent. and to have yielded ore equivalent to 200,000 tons of mercury.

regarded as veins), the cinnabar partly filling the pores of the quartzite but also metasomatically replacing the quartz grains.

*Idria, Austria.*—The cinnabar is in shales and marls and fissures in dolomite and there are many fault fissures. Metallic mercury occurs in the underlying clay slates.

*California.*—Along the coast ranges in a region of basalt andesite and rhyolite as fissure veins in sandstone widening into chambers,\* and as tabular masses between serpentine and sandstone.

*Mt. Amiata, Tuscany.*—Near trachyte in shales, limestones, sandstones and the trachyte itself.†

*Peru.*—Many deposits exist at Huancavelica and Yauli, Peru, in a region of slates, conglomerates and limestone near trachyte inclusions. They are now unimportant, formerly enormous producers.

*Avala, Servia.*—In porous quartz rock formed by alteration of a serpentine. Cinnabar, considerable mercury and some calomel.

*Nikilovka, Russia.*—In clay slate beneath sandstone and in fissures in coal seams.

*Siberia.*—With gold in the gravels near Beresowsk, Miask, etc.

*Terlingua, Texas.*—In vertical veins in limestone and in breccia. Notable for the chlorides and oxychlorides found there.

*Huitsuco, Mexico.*—As cinnabar and stibnite and in deeper levels much livingstonite.

### The Mercurial Tetrahedrite Deposits.

These may contain as much as 17 per cent. Hg, as at Dobschau and Iglo, Hungary, in veins in slate where the mercury is recovered by roasting and at several mines near Sumpter, Oregon. It occurs also at Schwatz, Tyrol; Landsberg, Palatinate; Mascara, Bosnia; and Ziks Mts., Hungary.

### MERCURY.

COMPOSITION.—Hg, with sometimes a little silver.

GENERAL DESCRIPTION.—A tin white liquid with metallic lustre. Usually found in little globules scattered in the gangue, or in cavities with cinnabar or calomel.

PHYSICAL CHARACTERS.—Opaque liquid. Lustre, metallic. Color, tin white. Sp. gr., 13.59.

BEFORE BLOWPIPE, ETC.—Entirely volatile. In matrass or closed tube may be collected in small globules. Soluble in nitric acid.

\* Lindgren, "Mineral Deposits," p. 467.

† Beyschlag, Vogt & Krusch (Truscott), p. 473.

**REMARKS.**—Native mercury is secondary and is found in many cinnabar deposits and sometimes in considerable quantity, as at the Pioneer and other mines in California; Terlingua, Texas; Idria, Austria; Avala, Servia. It may also occur without direct contact with the primary deposit as in marl, near Lüneburg, Hanover, and in cinnabar-free strata at Almaden, Spain.

### CINNABAR.—Natural Vermilion.

**COMPOSITION.**— $\text{HgS}$ , (Hg 86.2 per cent.).

**GENERAL DESCRIPTION.**—Very heavy, bright vermilion to brownish red masses of granular texture; more rarely small transparent rhombohedral crystals, or bright scarlet powder, or earthy red mass. Sometimes nearly black from organic matter.

**Physical Characters.** H., 2 to 2.5. Sp. gr., 8 to 8.2.

LUSTRE, adamantine to dull. OPAQUE to transparent.

STREAK, scarlet. TENACITY, brittle to sectile.

COLOR, cochineal red, scarlet, reddish brown, blackish.

**BEFORE BLOWPIPE, ETC.** — Completely volatilized without fusion if pure. With soda gives sulphur reaction. In closed tube yields a black sublimate, which becomes red when rubbed; if soda is used a metallic mirror is obtained instead of the black sublimate, and by rubbing with a splinter of wood globules of mercury may be collected. If cinnabar powder is moistened with hydrochloric acid and rubbed on *bright* copper the copper is made silver white. Soluble in aqua regia.

**SIMILAR SPECIES.** — Cinnabar is softer and heavier than hematite, cuprite, and rutile. It has a more decided red streak than crocoite or realgar, and differs from proustite in density and blowpipe reactions.

**VARIETIES.**—*Hepatic cinnabar* is a liver colored and massive or slaty mixture with bitumen.

*Tile ore* is bright red, impure, often with dolomite.

**REMARKS.**—Occurring as stated, p. 374. Usually primary, sometimes secondary, as in the mines near Sumpter, Oregon, where it results as an alteration of mercurial tetrahedrite. In this country it occurs in San Luis Obispo, Lake, San Benito, Napa, Santa Clara and other counties, California; Terlingua, Texas; Bald-Butte, Oregon. Humboldt and Nye counties, Nevada; Idaho, Utah and Washington also include deposits.

**METACINNABARITE.**— $\text{HgS}$  (Hg 86.2 per cent.). A variety, guadalcazarite, contains a little selenium and zinc. Amorphous black masses and hemispherical crystalline aggregates and little isometric crystals with rough faces. Streak black. H., 3. Sp. gr., 7.81. Tests as for cinnabar. It is probably secondary. Occurs

with cinnabar and is found in quantity in some of the Californian mines, especially massive at New Idria and in crystals at the Reddington Mine. Also found in mercury deposits of Idria, Austria; Guadalcázar, Mexico; Bay of Islands, New Zealand; and near Otero, Asturias, Spain.

**LIVINGSTONITE.**— $\text{HgSb}_2\text{S}_7$  (Hg 24.8, Sb 53.1, S 22.1 per cent.). Bright lead-gray prisms and columnar masses with metallic luster, resembling stibnite. Streak red. H., 2. Sp. gr., 4.1 to 4.8. It is very easily fusible, giving heavy white fumes. Even in *open* tube gives metallic mercury. Soluble in warm nitric acid with separation of antimony trioxide.

Found thus far only in Mexico, the principal deposit being at La Cruz Mine, Huizúcar, Mexico, where it constitutes practically the entire ore below the oxidized zone and has been worked to a depth of 500 feet. It is a "stock work" in limestone and the workings follow down an old geyser pipe.

Small amounts are found also at Guadalcázar, Mexico.

**ONOFRITE.**— $\text{Hg}(\text{S}, \text{Se})$ . In metallic blackish gray masses resembling chalcocite. Streak blackish gray. H., 2.5. Sp. gr., 7.6 to 8.1.

On coal decrepitates; gives copious fumes with selenium odor and lustrous sublimate, which will color the R. F. blue. In closed tube with soda gives mercury globules, without soda gives grayish black sublimate. Insoluble in hydrochloric acid, decomposed by aqua regia or chlorine gas.

It is apparently primary and occurs at Marysvale, Utah, with tiemannite as a four-inch vein in calcite and at San Onofre, Mexico, with calcite and barite.

**TIEMANNITE.**— $\text{HgSe}$  (Hg 71.7, Se 28.3 per cent.). It is found in black or nearly black fine-grained masses with metallic lustre and black streak. Rarely highly modified tetrahedral crystals. H., 2.5. Sp. gr., 7.1 to 8.5. Tests like onofrite.

It is probable primary and occurs in quantity in a vein in limestone, the ore sometimes 4 feet thick, near Marysvale, Utah. Found also at Zorge and Tilkerode, Harz, and in Argentina.

**COLORADOITE—COMPOSITION.**— $\text{HgTe}$  (Hg 61.5, Te 38.5 per cent.). It is found as dense masses of iron black material sometimes mottled with blue or purple H., 3. Sp. gr., 8.6.

On coal volatilizes, tinging R. F. green and giving white sublimate. In closed tube melts and gives three products, globules of mercury, drops of tellurium dioxide, and metallic tellurium nearest the assay. Soluble in boiling nitric acid with separation of tellurium oxide.

It is found in small amount with gold and silver tellurides in Boulder Co., Colorado and as a mixture with gold telluride at Kalgoorlie, West Australia.

#### **CALOMEL.—Horn Mercury.**

**COMPOSITION.**— $\text{Hg}_2\text{Cl}_2$  (Hg 84.9 per cent.).

**GENERAL DESCRIPTION.**—A gray or brown translucent mineral of the consistency of horn. Usually found as a coating in cavities with or near cinnabar. Sometimes in well-developed tetragonal forms  $c = 1.723$ .

**PHYSICAL CHARACTERS.**—Translucent. Lustre, adamantine. Color, gray, white, brown. Streak, white. H., 1 to 2. Sp. gr., 6.48. Very sectile.

**BEFORE BLOWPIPE, ETC.**—Volatilizes without fusion, yielding a white coating. In closed tube with soda forms a metallic mirror.

**REMARKS.**—Calomel is nowhere an important source of mercury, but is a secondary mineral first observed in the old deposits in the Palatinate and since that in many deposits, notably Avala, Servia; El Doktor near Zimapan, Mexico, and Terlingua, Texas.

**TERLINGUAITE.**— $\text{Hg}_2\text{ClO}$  (Hg 88.65, Cl 7.85, O 3.50 per cent.). Found as small transparent sulphur yellow monoclinic crystals (the name is also used for yellow pulverulent masses from same locality). It becomes olive green on exposure. H., 2 to 3. Sp. gr., 8.72.

On charcoal volatilizes completely, giving slightly pinkish sublimate. On closed tube with soda gives mercury sublimate. Soluble in nitric acid.

It occurs at the mercury mines of Terlingua, Texas, in a vugg in a calcite vein.

### THE SILVER MINERALS.

The minerals described are:

|                          |                     |   |              |
|--------------------------|---------------------|---|--------------|
| <i>Metal</i>             | <b>Silver</b>       | Ag  | Isometric    |
|                          | <b>Amalgam</b>      | $\text{Ag}_2\text{Hg}_2$ to $\text{Ag}_{20}\text{Hg}$ | Isometric    |
| <i>Sulphides</i>         | <b>Argentite</b>    | $\text{Ag}_2\text{S}$                                 | Isometric    |
|                          | <b>Stromeyerite</b> | $\text{CuAgS}$  | Orthorhombic |
| <i>Telluride</i>         | <b>Hessite</b>      | $\text{Ag}_2\text{Te}$                                | Isometric    |
| <i>Sulphoarsenite</i>    | <b>Proustite</b>    | $\text{Ag}_3\text{AsS}_3$                             | Hexagonal    |
| <i>Sulphoantimonites</i> | <b>Pyrargyrite</b>  | $\text{Ag}_3\text{SbS}_3$                             | Hexagonal    |
|                          | <b>Stephanite</b>   | $\text{Ag}_4\text{SbS}_4$                             | Orthorhombic |
|                          | <b>Polybasite</b>   | $(\text{Ag}, \text{Cu})_8\text{SbS}_8$                | Orthorhombic |
| <i>Halides</i><br>C<br>A | <b>Cerargyrite</b>  | AgCl  | Isometric    |
|                          | <b>Bromyrite</b>    | AgBr  | Isometric    |
|                          | <b>Embolite</b>     | $\text{Ag}(\text{Br}, \text{Cl})$                     | Isometric    |
|                          | <b>Iodyrite</b>     | AgI   | Hexagonal    |

Most of the silver of the world is obtained from argentiferous galenite and silver. Other common sulphides, such as sphalerite, pyrite, chalcopyrite, chalcocite, tetrahedrite, etc., and their oxidation products, especially cerussite, are often silver bearing. Sometimes it occurs in manganese or iron ores.

There are many other species containing silver among which are dyscrasite, which near Wolfach, Baden, is the chief silver ore and rare species like rittingrite, pyrostilpnite, polyargyrite, miargyrite, argyrodite, canfieldite, naumannite, and eucairite.

Argentiferous tetrahedrite occurs plentifully at Elko County, Nevada and Clear Creek, Colorado, and at Pulacayo, Bolivia; it is said to contain ten per cent. of silver.

### THE CUPELLATION TEST FOR SILVER.

The only satisfactory test is cupellation. Proceed as follows:

The iron cupel moulds, Fig. 403, are pressed full of finest washed bone ash, placed upon the anvil, the steel stamp, Fig. 403, placed

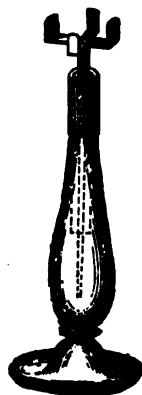
vertically upon the bone ash and struck with the hammer until the convex side of the stamp touches the inner side of the mold on all sides.

The mold is then placed on the cupel stand, Fig. 404, the cross cuts on the mold diagonal to the arms of the stand.

FIG. 403.



FIG. 404.



**ROASTING.**—The ore is first roasted on charcoal to remove volatile constituents and then one volume of the ore is mixed with one volume of borax glass and one to two volumes of test lead.

**FUSION.**—With the square borer a deep cylindrical hole is bored in the charcoal and made crucible shaped with a knife. The above mixture is carefully placed in this and heated in a pure not too strong R. F. till the borax and lead are fused and then the heat is made greater and the position of the coal occasionally changed until the assay turns over.

**SOFTENING.**—The R. F. is continued till no small lead globules are seen; it is then changed to a moderate O. F., which is directed on the lead in order to volatilize As, Sb, S, etc., and to oxidize other metals and make them unite with the borax.

When the slag spreads out and the lead begins to oxidize rapidly and rotate the blast is stopped, the assay cooled, the lead and slag separated by hammering.

**SCORIFICATION.**—The cupel, previously prepared, is now heated and the lead placed in the middle and fused in a strong O. F., more test lead being added if needed. After fusing a pure O. F.



is used and a moderate red heat. The blue point is not allowed to touch the lead and the oxide cools on the cupel around the lead. After awhile the position of the cupel stand is changed and the lead moves to a new spot, and this is continued until the lead is reduced to a button of, say, 2 mm. diameter, when it is allowed to cool on the litharge and then picked out.

If before the button is reduced to this size the oxide accumulates in such quantity as to interfere with the work the scorification had better be done on two or more successive cupels.

**FINE CUPELLATION.**—The second mold is then heated and the button placed near the (higher) left-hand edge, so that when it melts it will roll to the middle and free itself from adhering impurities.

The flame is then directed *on the bone ash around the button*, not on the button itself and this continued till all lead is removed and there remains only a silver white *spherical* button practically unaffected by further blowing.

#### ECONOMIC IMPORTANCE.

Ordinary silver ores contain less than one per cent. of the silver compounds distributed through various earthy and metallic minerals, and only show the true nature of the silver-bearing substance in occasional rich specimens. Frequently an ore will contain less than twenty ounces of silver per ton. On the other hand very rich ores occur and the wonderful deposits at Cobalt, Ont., are so rich that masses of pure native silver of several hundred pounds weight are sometimes secured.

In 1915 the United States produced 67,485,600 ounces, which is somewhat less than a third of the world's production.\*

The silver production† of the world for 1914 is given as 215,700,394 oz., of which this country produced 67,929,700 oz., or 31 per cent., and Canada, 27,544,231 oz., or 13 per cent. Mexico, the other great producer, in 1913 produced 49,461,103 oz. Australia, Germany, Belgium and Japan also produce in the millions of ounces.

The states producing‡ over one million ounces in 1914 were:

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\* *Engineering and Mining Journal*, 1916, p. 43.

† *Mineral Industry*, 1914, p. 282.

‡ *Mineral Resources U. S.*, 1914, p. 829 and 857.

|              | Ounces.    |                 | Ounces.   |
|--------------|------------|-----------------|-----------|
| Nevada.....  | 15,877,200 | Colorado.....   | 8,804,400 |
| Idaho.....   | 12,573,800 | Arizona.....    | 4,439,500 |
| Montana..... | 12,536,700 | California..... | 2,020,800 |
| Utah.....    | 11,722,000 | New Mexico..... | 1,771,300 |

The sources of the silver were:

|   | Ounces.    |
|---|------------|
| Dry and siliceous ores.....             | 28,000,875 |
| Argentiferous lead ores.....            | 19,302,081 |
| Copper ores (over 2½ per cent. Cu)..... | 14,829,828 |
| Zinc ores (over 25 per cent. Zn).....   | 145,264    |
| Lead zinc ores.....                     | 7,132,747  |
| Copper lead zinc ores.....              | 248,806    |
| Refining placer gold.....               | 152,128    |

**SMELTING.**—The extraction of silver by reduction with lead-ores in a water-jacket furnace, and the subsequent treatment has been referred to under lead, p. 317. When silver is a constituent of a copper matte it is recovered as a sedimentary product in the electrolytic refining of the copper. It is collected, together with any gold present, and further purified.

**AMALGAMATION.**—Native silver and the chloride, bromide and iodide can be extracted by the use of mercury while argentite and some other ores can be amalgamated by the addition of chemicals (copper sulphate, salt, etc.) and in other cases there may be a pre-roasting with salt to form chlorides.

The principle is that mercury will reduce certain compounds of silver to metal and unite with the silver, or if mercury is present and some other substance, as iron or copper, reduces the ore to silver, the mercury will collect it.

In pan amalgamation, less used than formerly, the finely-crushed ore, mixed to a pulp with water, is charged into a tub-like vessel, with an iron bottom and wooden sides. In this tub or pan there revolves a stirrer, with arms shaped to throw the pulp to the sides, from which it rolls back to the center. Attached to the arms are grinding shoes, which can be lowered so as to rub on the iron bottom or be raised free from it. Generally the pulp will be kept hot by steam, and no mercury will be added until the grinding is completed. During the grinding the metallic iron of the bottom and the shoes reduces the silver compound; although chemicals, such as salt, copper sulphate, potassium cyanide, etc., are sometimes added to assist.

In treating the rich native silver of Nipissing, Ontario, *a combination of amalgamation and cyaniding is used.*

The ore with an average content of 2,600 oz. Ag per ton, 6 per cent. Ni, 7–8 per cent. Co, and 40 per cent. As, is crushed to 70 mesh and ground for 9 hours, in a Krupp tube mill with 3½ tons ore, 4½ tons of mercury and a five per cent. cyanide solution.

It is then settled by gravity, the amalgam removed. The silver in the cyanide pulp is then precipitated on zinc shavings.

The excess mercury in either case is strained from the amalgam and the residue distilled off in retorts.

The refining involves melting. At Nipissing a reverberatory furnace is used and fifteen hours of oxidation, after which the silver is cast.

**HYDROMETALLURGY.**—Cyaniding is principally used in this country, dilute solutions of potassium cyanide rarely higher than 0.7 per cent. dissolving most silver minerals, but native silver only slowly and copper-bearing minerals like polybasite being objectionable. The leaching may continue 10 to 25 days, the silver then being precipitated on zinc dust or zinc shavings.

At Tonopah, Nevada, a mixed ore of polybasite, stephanite, argentite, some selenide of silver and secondary cerargyrite, iodyrite and native silver is crushed in gyratory crushers, then stamped in weak, warm KCy solutions (60 to 90° C.) and reduced to slimes in tube mills. It is then agitated 48 hours with addition of cyanide, lime and lead acetate, precipitated with zinc dust, filtered, dried and melted in graphite crucibles.

The uses of silver are too well known to need repeating.

#### **FORMATION AND OCCURRENCE OF SILVER DEPOSITS.**

Analyses show the presence of silver in minute amounts in both igneous and sedimentary rocks, and an estimate of .00001 per cent. is made for the crust of the earth. It is present in the magmatic segregations in gabbro, of Sudbury, Canada, and Scandinavia. The economic occurrences may be classified as follows:

##### **The "Young" Veins.**

These veins, which usually cross all rocks and obviously represent the latest stage of eruption, are always connected with the later eruptive\* rocks, often occurring in volcanic chimneys or "necks" and the adjacent rock and frequently by abnormal increases of temperature and presence of gases and hot springs showing their nearness to volcanic activities.

Mineralogically they differ from the older veins, in the occurrence together of notable amounts of both gold and silver minerals, the rich silver minerals are relatively abundant, especially the sulpho salts, proustite, pyrrargyrite, stephanite, tetrahedrite, and polybasite, while a quartz gangue and arsenic and antimony min-

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\* Especially andesite, dacite, often rhyolite, sometimes trachyte, phonolyte very seldom basalt. Beyschlag, Vogt & Krusch (Truscott), 516.

erals are common. The common sulphides occur, but nickel and cobalt are rare.

The great development\* of the young gold silver veins follows the mountain chains on each side of the Pacific, especially the Great Basin of the United States, Mexico, the Andes of Chili, Bolivia, etc., Japan, Philippines, Borneo and east coast of Asia.

Examples are:

*Pachuca, Mexico.*—Rich silver minerals in veins which cut andesite rocks and adjacent sediments. The gangue is quartz, rhodonite, rhodochrosite, and adularia. The silver minerals are argentite, stephanite, polybasite, with pyrite, galenite and sphalerite. In the upper portions limonite and the horn silvers (cerargyrite, bromyrite, etc.).

*Tonopah, Nevada.*—Rich silver minerals and gold. Veins in andesite and rhyolite. The gangue is quartz, rhodonite, adularia, etc. The silver minerals are principally argentite and polybasite with fine gold and in the oxidized zone much cerargyrite with iodyrite and bromyrite. Below this secondary argentite, polybasite and pyrargyrite.

*Chañarcillo, Chili.*—Rich silver minerals with copper minerals in limestone cut by augite porphyry and these rocks by the veins. In the upper levels silver, cerargyrite, bromyrite, malachite, siderite and barite in yellow clay; below this silver, argentite, polybasite, proustite, pyrargyrite; in the lower levels, sphalerite, galenite, arsenopyrite and pyrite.

*Pulacayo, Bolivia.*—Copper and lead minerals rich in silver but not the rich silver minerals to any extent. Veins in andesite and trachyte; the gangue, barite and quartz; the ore sphalerite, chalcopyrite, galenite and tetrahedrite all silver-bearing.

*Las Chispas, Sonora.*—Rich silver minerals in quartz veins in rhyolite and tuff. The first 200 feet cerargyrite and some gold; the lower levels stephanite in large masses, argentite, pyrargyrite and polybasite. Also argentiferous hematite.

### The " Old " Veins.

The silver and gold are less together than in the new veins and the old veins show in general† less connection with eruptive magmas and if observed the eruptives are old.

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\* Ibid., 515.

† Beyschlag, Vogt & Krusch (Truscott), 601.

Quartz silver lodes are rare in the old veins, dominant in the new. Mineralogically, probably because of longer erosion, since rich silver minerals occur near the surface, and the deposits worked are chiefly the deep primary ores of lead, zinc, copper. The gangue may include silicates, as at Kongsberg, axinite, elsewhere adularia, etc.

Examples are:

*Kongsberg, Norway.*\*—Rich silver minerals in narrow veins in gneiss and mica schist. The chief ore is silver, believed to be an alteration of earlier and now rare argentite and proustite. There is some stephanite. An unusual feature is numerous zeolites (stilbite, laumontite, harmotome, etc.).

*Cobalt, Ontario.*†—Metallic silver with cobalt minerals. Volcanic rocks, greenstones and schists, covered by conglomerate, are cut by "sills" of diabase. The ore is in veins in the later formed crevices, cutting all rocks and richest in the conglomerates. The principal silver mineral is native silver, but argentite, dyscrasite, and pyrargyrite also occur. These are with older formed smaltite, niccolite and other cobalt nickel and bismuth minerals.

Others are Freiberg, Saxony; Andreasberg, Harz; Příbram, Bohemia; Butte, Montana.

#### **Metasomatic Replacements.**

*Aspen, Colorado.*—Rich silver minerals with galenite and sphalerite replacing limestone. Limestone, dolomite and shales are cut by diorite and rhyolite porphyry. The mineral solutions ascending in the faults and fissures with gradually rising temperature deposited first veins of barite with some native silver, then rich silver ores argentite and polybasite, and finally the galenite and sphalerite as replacements of the limestone.

*Leadville, Colorado.*—Lead, zinc and manganese minerals with silver. Shales, limestones and quartzite are cut by granite porphyry intrusions. The ores are near the contact as replacements in the limestone, the primary ore being a granular mixture of sulphides. The upper levels are chiefly earthy mixtures of cerussite and cerargyrite in clayey limonite. Other metasomatic deposits‡ exist at Eureka, Nevada; Park City and Tintic Utah

\* Ibid., 660.

† Ibid., 666.

‡ Lindgren, "Mineral Deposits," p. 569.

Lake Valley, New Mexico; and with many copper and lead ores carrying silver.

**Contacts.**

*Broken Hill, New South Wales.\**—Lead and zinc minerals with silver minerals. A complex of gneiss, schists and quartz garnet rock is cut by diorite dikes. The contact deposit primary ores are sphalerite and galenite with garnet all through the ore. Near the surface there is chiefly manganiferous limonite, then a zone of silver-bearing cerussite with cerargyrite and silver and smaller quantities of embolite and iodyrite. Below this are the unaltered primary ores.

The veins of the Horn Silver Mine, Frisco, Utah, occur† at the contact of rhyolite and limestone.

**In Sediments.**

*Silver Reef, Utah.*—Rich silver minerals in Triassic sandstone due to secondary concentration‡ from argentiferous chalcocite. Above the water level cerargyrite, below the water level silver, argentite and argentiferous chalcocite.

**SILVER.—Native Silver.**

**COMPOSITION.**—Ag, sometimes alloyed with Au, Cu, Pt, Hg, Sb, Bi.

**GENERAL DESCRIPTION.**—A silver-white, malleable metal occurring in masses, scales and twisted wire-like filaments, penetrating the gangue or flattened upon its surface. Sometimes in isometric crystals, occasionally sharp but more frequently elongated and needle-like or in aborescent groups, each branch of which is composed of distorted forms in parallel position.

**Physical Characters.** H., 2.5 to 3. Sp. gr., 10.1 to 11.1.

LUSTRE, metallic.

OPAQUE.

STREAK, silver white.

TENACITY, malleable.

COLOR, silver white, tarnishing brown to nearly black.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses to a white metallic globule. Soluble in nitric or sulphuric acid, but from these it is

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\* Beyschlag, Vogt and Krusch (Truscott), 400.

† Ibid., 558.

‡ Lindgren, "Mineral Deposits," p. 374.

precipitated as a white curd-like precipitate by hydrochloric acid salt. The precipitate darkens on exposure to light.

**SIMILAR SPECIES.**—When tarnished, silver resembles copper or bismuth, but is distinguished by its silver-white streak from the former and by malleability and non-volatilization from the latter.

**REMARKS.**—Silver is said to be a primary mineral at Mogollon, Socorro Co., New Mexico, but is usually secondary and often found at considerable depth.\* It is found to some extent in nearly all deposits containing rich silver minerals and sometimes with lead or copper minerals. In some localities, as at Cobalt, Ontario, it is the dominating mineral.

The most celebrated mines where native silver is obtained are those of Kongsberg, in Norway, and Huantaya, Peru. Others are in Sonora, Mexico; the Michigan copper region; Boulder Co., Colorado; Butte, Montana; Poor Mans Lode, Idaho; Silver King, Arizona.

It is found in several localities with zeolites, as in Andreasberg, Harz; Arqueros, Chili; Kongsberg, Norway, and with the copper of Lake Superior.

#### AMALGAM.

**COMPOSITION.**— $\text{Ag}_2\text{Hg}_3$  to  $\text{Ag}_{11}\text{Hg}$ .

**GENERAL DESCRIPTION.**—A brittle, silver-white mineral of bright metallic lustre, which occurs in imbedded grains and indistinct isometric crystals.

**PHYSICAL CHARACTERS.**—Opaque, lustre metallic. Color and streak, silver white. H., 3 to 2.5. Sp. gr., 13.75 to 14.1. Somewhat brittle and cuts with a peculiar grating noise.

**BEFORE BLOWPIPE, ETC.**—On charcoal, partially volatilized, leaving malleable silver. In closed tube, yields mercury mirror. Soluble in nitric acid.

**REMARKS.**—Amalgam is frequently found in mercury mines in small amounts, as at Ober Moschel, Bavaria; Idria, Austria, and near Almaden, Spain. It is occasionally found in silver deposits, as at Arqueros, Chili, and the silver of Kongsberg, Norway, carries mercury.

#### ARGENTITE. — Silver Glance.

**COMPOSITION.**— $\text{Ag}_2\text{S}$ , (Ag 87.1 per cent.).

**GENERAL DESCRIPTION.**—A soft black mineral, of metallic lustre, which cuts like wax and occurs as masses, disseminated grains, or incrusting. Also found as isometric crystals, the cube, octahedron, or dodecahedron being most common and frequently grouped in parallel positions.

**Physical Characters.**—H., 2 to 2.5. Sp. gr., 7.2 to 7.36.

LUSTRE, metallic.

OPAQUE.

STREAK, lead gray.

TENACITY, very sectile.

COLOR, lead gray to black or blackish gray.

**BEFORE BLOWPIPE, ETC.**—On charcoal, swells, fuses, yields

\* At Aspen, Colorado, 900 feet below surface. Ibid., 586.

fumes of sulphur dioxide, and finally malleable silver. Soluble in nitric acid, with separation of sulphur.

**SIMILAR SPECIES.**—Differs from other soft black minerals in cutting like wax and in yielding malleable silver on heating. Differs from cerargyrite in solubility in nitric acid.

**REMARKS.**—Is both primary and a product of secondary enrichment.\* Large quantities have been obtained at Tonopah and Comstock and Austin, Nevada; Pachuca, Mexico; Chañarcillo, Chili; and Aspen, Colorado, and fine crystals from Arizpe, Sonora, and Freiberg, Saxony.

#### STROMEYERITE

**COMPOSITION.**—CuAg S, (Ag 53.1; Cu 31.1 per cent.).

**GENERAL DESCRIPTION.**—Dark gray metallic masses resembling chalcocite. Rarely twinned orthorhombic crystals.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, metallic. Color, dark gray. Streak, same as color. H., 2.5–3. Sp. gr. 6.2–6.3.

**BEFORE BLOWPIPE, ETC.**—Reacts for copper, silver and sulphur.

**REMARKS.**—Stromeyerite is found in quantity at the Yankee Girl Mine, Ouray Co., Colorado, and in smaller amounts at other localities in Colorado, California, Nevada and Arizona. Foreign occurrences exist in Siberia, Silesia, Peru, Argentina and Tasmania.

#### HESSITE.

**COMPOSITION.**—(Ag·Au)<sub>2</sub>Te, grading from hessite, Ag<sub>2</sub>Te (Ag 63 per cent.) to petzite, in which there is 20 to 25 per cent. of gold.

**GENERAL DESCRIPTION.**—Fine-grained, gray, massive mineral, of metallic lustre. Also coarse granular, and in small, indistinct, isometric crystals.

**Physical Characters.** H., 2 to 2.5. Sp. Gr., 8.3 to 8.6.

LUSTRE, metallic.

OPAQUE.

STREAK, black.

TENACITY, slightly sectile.

COLOR, between steel gray and lead gray.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses to a black globule, with white silver points on its surface. If powdered and dropped into boiling concentrated sulphuric acid, the acid is colored an intense purple.

**REMARKS.**—Hessite has been an important ore in Boulder Co. and La Plata Co., Colorado, and occurs in Calaveras Co., California, and Baker Co., Oregon. The best known occurrences are in Transylvania, Hungary. Also found in Altai, Siberia, and Arqueros, Chili.

\* In the zone of enrichment it is usually accompanied by the sulpho salts such as proustite, pyrrargyrite and stephanite.



## THE SULPHO-SALTS OF SILVER.

The sulpho-salts of silver, proustite, pyrargyrite, stephanite, polybasite, frequently occur together and with argentite and silver form the enriched zone in many mines. Their mode of formation is not understood and one of them at least, polybasite, is believed to sometimes be primary.

## PROUSTITE.—Light Ruby Silver.

COMPOSITION.— $\text{Ag}_3\text{AsS}_3$ , (Ag 65.4, As 15.2, S 19.4 per cent.). Sometimes containing a little antimony.

GENERAL DESCRIPTION.—A scarlet vermilion mineral, either translucent or transparent, with a scarlet streak. Usually occurs disseminated through the gangue or as a stain or crust. Rarely in small hexagonal crystals.

CRYSTALLIZATION.—Hexagonal. Hemimorphic class, p. 52. Axis  $c = 0.804$ . Fig. 405 shows a typical crystal according to Miers. Optically —, with very high indices of refraction ( $\gamma = 2.979$  for red light).



Physical Characters. H., 2 to 2.5. Sp. gr., 5.57 to 5.64.

LUSTRE, adamantine, brilliant. TRANSLUCENT to transparent.

STREAK, scarlet.

TENACITY, brittle.

COLOR, scarlet vermilion.

BEFORE BLOWPIPE, ETC.—On charcoal, fuses, yields sulphurous and garlic odors and malleable silver. In closed tube, fuses and yields slight red sublimate, yellow when cold. Decomposed by nitric acid, leaving a white residue. In powder, is turned black by potassium hydroxide solution, and partially dissolved on boiling. Hydrochloric acid precipitates from this a lemon yellow arsenic sulphide.

SIMILAR SPECIES.—Differs from pyrargyrite in scarlet streak, and from cuprite and cinnabar by garlic odor when heated.

REMARKS.—Proustite is less abundant than pyrargyrite and probably than polybasite and may accompany them below the oxidized zone. Famous deposits were worked at Chañarcillo and Caracoles, Chili, and Guanajuato, Mexico, and other well-known localities are St. Andreasberg, Harz, and the silver cobalt deposits at and near Freiberg, Saxony, and Joachimsthal, Bohemia. Most abundant in the United States at Poor Man's Lode, Idaho; Austin, Nevada, and in Gunnison County, Colorado, at the Ruby silver district.

**PYRARGYRITE.—Dark Ruby Silver.**

**COMPOSITION.**— $\text{Ag}_3\text{SbS}_3$ , (Ag 59.9, Sb 22.3, S 17.8 per cent.). Often with small amounts of arsenic.

**GENERAL DESCRIPTION.**—A nearly black mineral, which is deep red by transmitted light and has a purplish-red streak. Usually occurs massive or disseminated, or in thin films, sometimes in crystals.

FIG. 406.



**CRYSTALLIZATION.**—Hexagonal. Hemimorphic class, p. 52. Axis  $c = 0.789$ . Prismatic crystals, with rhombohedral or scalenohedral terminations. Frequently twinned. Fig. 406 shows a typical crystal according to Miers. Optically —, with very high indices of refraction ( $\gamma = 3.084$  for red light).

**Physical Characters.** H., 2.5. Sp. gr., 5.77 to 5.86.

LUSTRE, metallic, adamantine.

TRANSLUCENT to opaque.

STREAK, purplish red.

TENACITY, brittle.

COLOR, black or nearly so, but purple red by transmitted light.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses easily, spirts, evolves dense white fumes and leaves malleable silver. A white sublimate forms. In closed tube, yields black sublimate, red when cold. Soluble in nitric acid, with separation of sulphur and antimony trioxide. In powder, is turned black by a solution of potassium hydroxide, and on boiling it is decomposed; the solution deposits an orange precipitate on addition of hydrochloric acid.

**SIMILAR SPECIES.** — The streak is purplish red, differing from the scarlet of proustite. The streak and silver reaction distinguish it from cuprite, cinnabar and realgar.

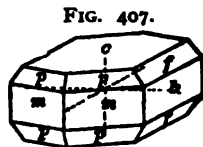
**REMARKS.**—Pyrargyrite is more abundant than proustite and is found in important quantities in many localities as at Guanajuato and Sonora, Mexico; Chafarillo and Caracoles, Chili; Poor Man's Lode, Idaho; Austin and Reese River, Nevada; Stockton Hill District, Arizona. Other well-known localities are St. Andreasberg, Harz; Příbram, Bohemia; Freiberg, Saxony; Schemnitz and Kremnitz, Hungary.

**STEPHANITE.—Brittle Silver Ore.**

**COMPOSITION.**— $\text{Ag}_3\text{SbS}_4$ , (Ag 68.5, Sb 15.2, S 16.3 per cent.).

**GENERAL DESCRIPTION.**—Fine-grained, iron-black mineral, with metallic lustre, often disseminated through the gangue. Sometimes in short six-sided prismatic crystals. It is soft, but brittle.

**CRYSTALLIZATION.**—Orthorhombic. Axes  $a:b:c = 0.629 : 1 : 0.685$ . Short prismatic crystals often twinned in pseudo-hexagonal shapes. Unit pyramid  $p$ , unit prism  $m$ , the pinacoids  $b$  and  $c$  and the dome  $f = (\infty a : b : 2c)$ ;  $\{021\}$ ; are the commoner forms. Supplement angles  $mm = 64^\circ 21'$ ;  $pp = 49^\circ 44'$ ;  $cf = 53^\circ 53'$ .



**Physical Characters.** H., 2 to 2.5. Sp. gr., 6.2 to 6.3.

LUSTRE, metallic.

OPAQUE.

STREAK and COLOR, black.

TENACITY, brittle.

**BEFORE BLOWPIPE, ETC.**—On charcoal, fuses easily, yielding white fumes and coat and odor of sulphur dioxide, finally leaves malleable silver. Soluble in nitric acid, with residue of sulphur and antimony trioxide. With potassium hydroxide, reacts like pyrrargyrite.

**SIMILAR SPECIES.**—It is more brittle than argentite and softer than tetrahedrite.

**REMARKS.**—Stephanite is sometimes secondary after polybasite. It occurs at Las Chispas, Sonora, Mexico, in large masses and crystals with argentite, pyrrargyrite and polybasite. It was abundant at the Comstock and Reese River, Nevada, and at Red Jacket, Gunnison Co., and other localities in Colorado. Found at the Saxon, Bohemian, Hungarian and German localities mentioned under proustite and pyrrargyrite; also at Pachuca, Mexico; Arqueros, Chili, and elsewhere.

### POLYBASITE.

**COMPOSITION.**— $(Ag.Cu)_2SbS_4$ , often with some Sb replaced by As.

**GENERAL DESCRIPTION.**—A soft, iron-black mineral, of metallic lustre, best known in six-sided tabular prisms, with bevelled edges. In thin splinters it is cherry red by transmitted light. Orthorhombic.

**PHYSICAL CHARACTERS.**—Nearly opaque. Lustre metallic. Color and streak, black, but the powder is red by transmitted light. H., 2 to 3. Sp. gr., 6 to 6.2. Brittle.

**BEFORE BLOWPIPE, ETC.**—Fuses with spitting. Gives off odor of garlic sometimes, but always yields heavy white fumes and odor of sulphur dioxide, and leaves malleable button, which in beads reacts for copper, or, if dissolved in nitric acid, will yield a flocculent white precipitate on addition of hydrochloric acid. In closed tube, fuses very easily, but yields no sublimate. Soluble in nitric acid.

**REMARKS.**—A large deposit of polybasite at the Molly Gibson Mine, Aspen, Colorado, has been called a primary replacement in limestone. At Tonopah, Nevada, argentite and polybasite are the principal ores. At Neihart, Montana, polybasite is intimately associated with the galena and sphalerite.

In many localities, however, polybasite is part of the secondary enrichment, as at Las Chispas, Sonora, Mexico; Georgetown, Colorado; Chafarcillo, Chili.

Occurs at Freiberg, Saxony, and Příbram, Bohemia.

#### THE SILVER HALOIDS.

The compounds of silver with chlorine bromine and iodine are usually in the "gossan" of silver deposits or of silver lead deposits and are probably due to chiefly the precipitating action of surface waters on silver sulphate solutions though sometimes there is direct replacement of argentite by cerargyrite. In general the chloride cerargyrite is dominant but not always and many so-called cerargyrites are embolite.

#### CERARGYRITE.—Horn Silver.

COMPOSITION.—AgCl, (Ag 75.3 per cent.).

GENERAL DESCRIPTION.—A soft, grayish-green to violet crust or coating of the consistency and lustre of horn or wax. Rarely in cubic crystals.

Physical Characters. H., 1 to 1.5. Sp. gr., 5 to 5.5.

LUSTRE, waxy, resinous.

TRANSLUCENT.

STREAK, shining white.

TENACITY, very sectile.

COLOR, pearl gray or greenish, darkens on exposure to light, becoming violet, brown or black.

BEFORE BLOWPIPE, ETC.—Fuses very easily, yields acrid fumes and a globule of silver. Rubbed on a moistened surface of zinc or iron, it swells, blackens and the surface is silvered, and the mineral is reduced to spongy metallic silver. In matrass, with acid potassium sulphate, yields a globule, yellow hot, white cold, and made violet or gray by sunlight. Insoluble in acids, soluble in ammonia. On coal, with oxide of copper, yields azure-blue flame.

SIMILAR SPECIES.—Bromyrite, embolite and iodyrite are most easily distinguished by tests with acid potassium sulphate. It differs from argentite in color and insolubility in nitric acid.

REMARKS.—It is not abundant in Europe or Asia but is especially prominent in the upper portions of the "Young" veins, p. 382, famous localities being Pachuca and Las Chispas, Mexico; Chafarcillo Caracoles, Chili, and Broken Hill, New South Wales. In the United States its most celebrated localities have been Poor Man's Lode, Idaho and Horn Silver, Utah; other noteworthy localities being Leadville, Colorado; Tonopah, Nevada; Lake Valley, New Mexico and the chloride districts of Arizona.

**BROMYRITE.—Bromargyrite.**

COMPOSITION.—AgBr, (Ag 57.4 per cent.).

GENERAL DESCRIPTION.—Like cerargyrite, except that the color is bright yellow to grass green or olive green. H., 2 to 3. Sp. gr., 5.8 to 6. Usually found in small concretions and little altered by exposure.

BEFORE BLOWPIPE, ETC.—Like cerargyrite, except that in matrass with acid potassium sulphate a little bromine vapor is evolved, coloring the fluid salt yellow, and the fused bromyrite sinks as a dark red, transparent globule, which, on cooling, becomes opaque and deep yellow, and when exposed to sunlight becomes dark green.

REMARKS.—Bromyrite occasionally accompanies cerargyrite and at Chaffarcillo, Chili, the cerargyrite, bromyrite and embolite are said to have been in closely the proportion of the Cl, Br and I in sea water. It occurs at Plateros, Mexico, and Huelgoat, Brittany, and in this country has been of economic importance in Elko Co., Nevada and Sierra Co., New Mexico.

**EMBOLITE.**

COMPOSITION.—Ag(Cl.Br). Isomorphic mixtures of the chloride and bromide.

GENERAL DESCRIPTION.—Intermediate between cerargyrite and embolite. Color, green to yellow, darkening on exposure. H., 1 to 1.5. Sp. gr., 5.31 to 5.81.

BEFORE BLOWPIPE, ETC.—The acid potassium sulphate fusion is like that of cerargyrite or that of bromyrite, as the bromine is small in amount or plentiful.

REMARKS.—Embolite is said to be more abundant than cerargyrite in some of the Chilian mines and has been found in important quantity in Lake Co., Colorado; the Pearce District, Arizona, and Sierra Co., New Mexico; Shafter, Texas; and Broken Hill, New South Wales.

**IODYRITE.—Iodargyrite.**

COMPOSITION.—AgI, (Ag 46, I 54 per cent.).

GENERAL DESCRIPTION.—A yellow or yellowish-green, wax-like mineral, occurring massive or in thin flexible scales or in hexagonal crystals.

PHYSICAL CHARACTERS.—Translucent. Lustre, resinous, wax-like. Color, gray, yellow or yellowish green. Streak yellow. H., 1. Sp. gr., 5.6 to 5.7. Sectile.

BEFORE BLOWPIPE, ETC.—Fuses very easily, spreads out and gives pungent odor. In closed tube, fuses and becomes deep orange in color, but cools yellow. With oxide of copper, colors flame intense green. In matrass with acid potassium sulphate, yields violet vapor and deep-red globule, which is yellow when cold and not changed by exposure to sunlight.

REMARKS.—Iodyrite is found at Broken Hill, New South Wales; Tonopah, Nevada, and Sierra Co., New Mexico. It is more abundant in certain mines in Chili, as at Algodones.

**THE GOLD MINERALS.**

The minerals described are:

|                   |                   |  |                  |
|-------------------|-------------------|--|------------------|
| <i>Metal</i>      | <b>Gold</b>       | <b>Au</b>  | <b>Isometric</b> |
| <i>Tellurides</i> | <b>Sylvanite</b>  | (Au.Ag) <sub>2</sub> Te <sub>2</sub>   | Monoclinic       |
|                   | <b>Calaverite</b> | (Au.Ag) <sub>2</sub> Te <sub>2</sub>   |                  |
|                   | <b>Krennerite</b> | (AuAg) <sub>2</sub> Te <sub>2</sub>  | Orthorhombic     |
|                   | <b>Petsite</b>    | (Au.Ag) <sub>2</sub> Te  | Isometric        |
|                   | <b>Nagyagite</b>  | Au <sub>2</sub> Pb <sub>10</sub> Sb <sub>7</sub> Te <sub>6</sub> Si <sub>4</sub> | Orthorhombic     |

Gold selenide\* of unknown formula occurs in considerable quantity at Radjang Lebong, Sumatra and at Republic, Washington (in a gangue of fine-grained quartz). Gold amalgam in small amounts occurs occasionally.†

The most important of all gold ores is auriferous pyrite and gold also occurs in important quantities in chalcopyrite, arsenopyrite and stibnite. Other minerals in which gold has been included are sphalerite, smaltite, niccolite, tetradymite, aikinite and silicates such as hornblende, feldspar, epidote, garnet. It is frequently alloyed with silver, sometimes with bismuth, mercury or palladium.

#### ECONOMIC IMPORTANCE.

The gold production of the world‡ for 1915 was \$470,979,890, Africa supplying 46 per cent. of all and North America 28 per cent. The great producers were:

|                         |               |                    |              |
|-------------------------|---------------|--------------------|--------------|
| Transvaal.....          | \$188,397,707 | Rhodesia.....      | \$18,852,130 |
| United States.....      | 98,891,000    | Mexico.....        | 16,975,000   |
| Australia.....          | 44,368,013    | Canada.....        | 15,875,005   |
| Russia and Siberia..... | 26,750,000    | British India..... | 11,699,385   |

The producers of the remainder, about \$50,000,000, were, in order of importance: South America, West Africa, Japan, East Indies, Central America, China, Madagascar and France.

In this country the leading regions were:

|                   |              |                 |             |
|-------------------|--------------|-----------------|-------------|
| California.....   | \$23,005,800 | Montana.....    | \$4,763,100 |
| Colorado.....     | 22,191,200   | Arizona.....    | 4,107,400   |
| Alaska.....       | 16,626,700   | Utah.....       | 3,494,800   |
| Nevada.....       | 11,314,700   | Oregon.....     | 1,739,400   |
| South Dakota..... | 7,397,400    | New Mexico..... | 1,430,000   |

The percentages according to kind of ore and method of treatment in 1914 were:

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\*Lindgren's "Mineral Deposits," p. 493. According to Beyschlag, Vogt and Krusch, the selenium is associated with the silver rather than the gold, p. 589. Selenium is also associated with the gold at Falun, Sweden, and with the silver and gold deposits of Tonopah, Nevada, and is said to constitute several per cent. of the composition of the Western Australian gold tellurides (see Beyschlag, Vogt and Krusch, p. 593).

† California, Colombia, Urals, Australia, etc.

‡ *Engineering and Mining Journal*, 1916, p. 43.

|                               |        |       |
|-------------------------------|--------|-------|
| Placers.....                  | 25.3   | 25.3  |
| Dry and siliceous ores.....   |        | 66.5  |
| By amalgamation.....          | 20.9   |       |
| By cyanidation.....           | 31.4   |       |
| By chlorination.....          | .2     |       |
| By smelting.....              | 14.0   |       |
| Copper, lead, etc., ores..... |        | 8.2   |
| By smelting.....              | 8.2    |       |
|                               | 100.00 | 100.0 |

#### FORMATION AND OCCURRENCE OF THE GOLD DEPOSITS.

Gold is found in small amounts in many igneous rocks apparently as a primary mineral† and in the schists and gneisses it has occasionally been deposited before metamorphism and intercrystallized with their silicates.‡

The relative importance of the different classes of deposits—the gravel deposits of each being included—are given§ as

|  |              |
|--|--------------|
| Witwatersrand conglomerate about ..... | 35 per cent. |
| Old gold veins about.....              | 33 "         |
| Young gold veins about.....            | 25 "         |
| Contact deposits about.....            | 1/5 "        |

#### Contact Deposits.

Contacts involving much gold are relatively rare.

*Reichenstein, Silesia.*||—Serpentine and limestone contacts with granite. The ore löllingite and arsenopyrite carrying gold. Contact minerals diopside, titanite, vesuvianite, apatite and fluorite present.

*Cable Mine, Montana.*¶—Free gold in calcite occurs at the contact of limestone and quartz monzonite. Associates are quartz, pyrrhotite, pyrite, amphibole, actinolite, garnet, magnetite and green mica.

*Nickel Plate Mine, British Columbia.*\*\*—At the contact of limestone, shales and quartzites with gabbro and diorite there are

\* Mineral Resources U. S., 1914, p. 862.

† Cordilleras of Chili. Aplite dikes in the Winscott Mine, Montana, etc.

Beyschlag, Vogt and Krusch (Truscott), 346. Embedded in fresh quartz and feldspar of a granite from Sonora, Mex., Lindgren, "Mineral Deposits," p. 10.

‡ Ayrshire Mine, Mashonaland, Lindgren, p. 13.

§ Beyschlag, Vogt & Krusch, p. 646.

|| Ibid., 404.

¶ Ibid., 697.

\*\* "Mineral Deposits," p. 696.

found free gold and gold-bearing arsenopyrite, with pyrrhotite, pyrite, chalcopyrite, sphalerite and tetradymite. Associates are garnet (andradite), pyroxene, epidote, axinite.

Other occurrences with copper ores occur on the eastern slope of the Sierra Madre, Mexico.

### The Young Veins.

The characteristics of the young gold and silver veins are described, p. 382, under silver. The examples there given are of mines with dominant silver.

These grade into veins rich in native gold or gold pyrite or telluride of gold, that is, these veins are connected with recent igneous intrusions and are formed after the main intrusion by gold-bearing emanations from the interior magma, which fill fissures and often also replace existing minerals and deposit their load chiefly of quartz, free gold, gold-bearing pyrite or the gold tellurides. Examples of such deposits are:

*Goldfields, Nevada.*\*—Numerous fissures in highly altered rock containing 15.73 alunite in a district covered by flows of dacite, andesite and rhyolite. The ores are native gold, and tellurides with pyrite, marcasite, bismuthinite, etc., in a flint-like quartz. Silver is very subordinate.

*Transylvania, Hungary.*—(The most important gold deposits of Europe.) Andesite and dacite breaking through country rock. The gold largely combined with tellurium.

At Nagyag there are veins in the andesites, trachytes and dacites and in the sedimentary rocks. Many veins are barren, others carry sylvanite, krennerite and nagyagite and rarely free gold and tetrahedrite in a non-crystalline quartz gangue. Still others carry nagyagite, sylvanite, and other tellurides in a carbonate gangue (calcite, dolomite, siderite, rhodochrosite).

At Offenbanya the veins occur in a dacite, and some contain nagyagite and sylvanite in a gangue of quartz and calcite.

*Cripple Creek, Colorado.*—(Tellurides.) A red granite† broken through by volcanic rocks, the ore occurring in many roughly radial narrow veins concentrated within the core of an old volcano and filled with a gangue of quartz and fluorite containing and often

\* Lindgren, "Mineral Deposits," p. 507.

† Lindgren, "Mineral Deposits," p. 489.



intergrown with calaverite and sometimes sylvanite with small amounts of pyrite, sphalerite, tetrahedrite, stibnite and molybdenite. Free gold is found only in the oxidized zone.

*Western Australia.*—(Tellurides.) The various mines of this province have yielded over \$600,000,000 in gold. At Kalgoorlie the deposits are veins in amphibolite or contacts between amphibolite and granites. Some of the veins contain no tellurides, others contain pale yellow massive calaverite and nearly black massive, lustrous coloradoite (kalgoorlite); the pyrite is disseminated in small crystals. In the oxidized zone there is much secondary gold.

Associated are the common sulphides and occasionally scheelite and chlorite, albite, tourmaline, calcite, dolomite, roscoelite, magnetite, hematite, etc.

*Sumatra.*†—(Selenides.) At Radjang Lebong in a region of hot springs occur large gold-silver veins in a gangue of banded quartz and chalcedony. The ore is disseminated finely, or if rich appears as dark dendritic crusts not unlike the naumannite,  $\text{Ag}_2\text{Se}$ , of Tilkerode. Analyses of the bullion show 4.35 per cent. of selenium.

### The "Old " Gold Veins.

In these veins‡ the filling is sharply separate from the country rock and is principally quartz carrying auriferous pyrite. There is little gold in the oxidation zone, but lower there may be a zone of enrichment with gold coating or filling cracks in the sulphides or fissures in the quartz. The veins are rarely of great width and are usually simple. Tourmaline and other silicates are more common and tellurium is rare.

Economically important localities are:

*California.*§—Along the west flank of the Sierra Nevadas. The mountains, which contain few veins, are principally massive granodiorite. The veins are generally in the sediments clustered around smaller intrusions and following long lines of fracturing

\* These are placed by Lindgren under high temperature deposits, last cit., p. 647, but by Beyschlag, Vogt and Krusch, p. 590, under the young gold silver lodes.

† Beyschlag, Vogt and Krusch (Truscott), p. 589.

‡ Ibid., p. 601.

§ Lindgren, "Mineral Deposits," p. 530.

such as the "mother lode" 130 miles long,  $6\frac{1}{2}$  miles wide, the "serpentine belt" 70 miles long, etc. The ore is native gold, always with gold-bearing pyrite, sometimes with gold tellurides (calaverite, sylvanite, petzite, etc.), and sometimes chalcopyrite, sphalerite, galenite, tetrahedrite. The gangue is quartz and small amounts of calcite and dolomite. Mariposite, a chromium mica, is common, roscoelite and scheelite local.

*Victoria, Australia.*\*—In several districts such as Bendigo and Ballarat slates and quartzites are intruded by quartz monzonite. At the folds of the slates and sandstone cavities develop which have been filled by quartz, forming "saddle-shaped" masses carrying native gold, pyrite, arsenopyrite and sometimes small amounts of other sulphides. The slates also carry irregular bodies. Somewhat similar but small deposits are found in the anticlinal folds of slate and quartzite in Nova Scotia.

*Passagem, Brazil.*—This great deposit is regarded as a twice-shattered pegmatite dike.† The first fissures filled with tourmaline and sericite and the later fissures with ore-bearing solutions. The ore is milk-white quartz containing tourmaline, free gold alloyed with bismuth, gold-bearing arsenopyrite and some pyrrhotite and pyrite. Associated are contact minerals, amphibole (cummingtonite), staurolite, andalusite, cyanite, garnet, biotite and plagioclase.

*Homestake, South Dakota.*—This great deposit, which yielded in 1914 ore to the value of \$6,160,161,‡ consists of large lenses§ of altered rock carrying the ore and embedded in unaltered clay slate. The ore is fine-grained free gold in quartz with pyrite, pyrrhotite, arsenopyrite, etc., and much brownish amphibole (cummingtonite) and some garnet.

*Beresowsk, Urals.*||—Narrow "ladder" veins crossing decomposed fine granite dikes nearly at right angles and extending a little into the surrounding schists. The ore is free gold, gold-bearing pyrite and small amounts of aikinite, chalcopyrite and galenite. The gangue is quartz with much tourmaline.

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\* Lindgren, "Mineral Deposits," p. 543.

† Ibid., p. 732.

‡ Mineral Resources U. S., 1916, p. 844.

§ Lindgren, p. 638.

|| Beyschlag, Vogt and Krusch (Truscott), p. 629.

**Metasomatic Replacements.**

These are comparatively rare.

Examples in which the gold-bearing emanations have replaced existing minerals as well as filled fissures are:

The refractory siliceous ores of Black Hills, S. D., replacing shaly limestone.\*

The ores of Delamar, Nevada,† in which the original gangue of calcite has been replaced by cellular quartz.

*Mt. Morgan, Queensland.*—A conical hill of gold-bearing quartzite traversed by dikes, nearly the entire hill being workable gold ore. Ore is gold and pyrite in quartz of many varieties. In one portion a foam-like siliceous sinter, which floated on water, in another a crushed sugar-like powder, in another solid, in others stalactitic. Rickard regards it as shattered country rock saturated with mineral solutions and in part replaced by gold-bearing quartz.

*Southern Appalachians.*—Lindgren describes these‡ as "fissure veins and replacements in schists." Many stringers and lenses of massive quartz occur in the crystalline schists usually parallel to the foliated structure. Some contain native gold with pyrite or arsenopyrite and less commonly other sulphides. Tellurides occur locally. The associates include chlorite, ilmenite, magnetite, tourmaline, and sometimes gahnite and garnet.

At Dahlonga, Ga., the amphibolite wall is altered to pale red garnet carrying gold and dark green mica and the gold is with tetradymite.

**Gold-Bearing Conglomerates.**

The original material of a gold-bearing conglomerate may have been the detritus of gold-bearing veins in which case the gold is usually in rounded grains or nuggets of free gold. Or the gold may have been of later origin and have entered through fissures or by infiltration.

*The Conglomerates of Witwatersrand.*—The origin of the gold in the conglomerates of Witwatersrand or "Rand" in the Transvaal is in doubt.|| It is believed that the mineralization was later than

\* J. D. Irving, *Jour. Canadian Institute*, 1910, "Replacement Ore Bodies."

† Lindgren, "Mineral Deposits," p. 482.

‡ Beyschlag, Vogt and Krusch (Truscott), p. 642.

§ "Mineral Deposits," p. 634.

|| *Ibid.*, p. 220.

the formation of the conglomerate and traceable to eruptive diabase. This deposit, which has yielded nearly \$2,000,000,000, consists of pebbles of quartz cemented by quartz, sericite and chlorite and with nodules and coatings of pyrite and specks of crystalline gold often intergrown with the pyrite.

*The Homestake, S. Dakota, Conglomerate.*—This is regarded as an ancient gold gravel resulting from the erosion of the neighboring gold veins.

### Gold "Placers" or "Gravels."

The rocks containing gold deposits are broken down by weathering and the fragments and undissolved material, collect as sand and gravel in the valleys, rivers and beaches.

The gold-bearing sulphides yield free gold, iron hydroxide and soluble salts; there is some solution, possibly by ferric sulphate and redeposition,\* and some concentration by gravity.

Practically every gold district has its placer deposits, which are commonly first worked, the important ones usually from the "Old" gold veins.

The mineral associates are always characterized by relative insolubility and hardness and often high specific gravity—"black sand" (magnetite, or ilmenite), quartz, garnet, zircon, monazite, cassiterite, platinum, iridosmine, and the so-called gem stones.

The largest "placer" deposits still producing today are in Alaska, California (and other American states, especially Montana, Idaho and Colorado), British Columbia, Siberia, Australia, Guiana, Colomba, Belgian Congo. Many other countries yield considerable amounts.

### GOLD. — Native Gold.

COMPOSITION. — Au, usually alloyed with Ag, and sometimes Cu, Bi, Rh, or Pd.

GENERAL DESCRIPTION. — A soft malleable metal with color and streak varying from golden yellow to yellowish white according to the silver contents. It is found in nuggets, grains, or scales, usually so disseminated as to be apparent only on assay. Rarely in distinct isometric crystals, but more frequently in skeleton crystals or

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\* Proof of chemically precipitated gold exhibited in the Paris Exhibition from western Australia gravels included gold on tree roots, gold in fine cracks in iron ochre, gold in stalactites of calcite and ochre and crystals of gold on secondary cobalt manganese ore. Beyschlag, Vogt and Krusch (Truscott), p. 1199.

FIG. 408.



Gold, Butte Co., Cal. Columbia University.

distorted and passing into wire-like, net-like, and dendritic shapes. Also occurs included in pyrite, sphalerite, galenite, pyrrhotite, and arsenopyrite.

**Physical Characters.** H., 2.5 to 3. Sp. gr., 15.6 to 19.3.

LUSTRE, metallic.

OPAQUE.

STREAK, like color.

TENACITY, malleable.

COLOR, golden yellow to nearly silver white.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses to a bright yellow button insoluble except in aqua regia. Any silver present will separate from the solution as a white curd-like precipitate. If the solution is evaporated to a thick syrup and diluted with water and heated with stannous chloride it becomes purple, and a purple precipitate settles.

**SIMILAR SPECIES.**—Chalcopyrite, pyrite, and scales of yellow mica are mistaken for gold, but differ entirely in specific gravity, streak, brittleness, and solubility in acids.

**THE GOLD TELLURIDES.**—Calaverite, Sylvanite, Krennerite, Petzite, Nagyagite.

**COMPOSITION.**—Calaverite and the rarer sylvanite and krennerite have the same general formula  $(\text{Au.Ag})\text{Te}_2$ ; petzite is  $(\text{AuAg})_2\text{Te}$  and nagyagite  $\text{Au}_8\text{Pb}_{10}\text{Sb}_2\text{Te}_6\text{S}_{16}$ .

**GENERAL DESCRIPTION.**—The gold tellurides, are in the massive granular state, are of dull appearance and often intermixed with pyrite. Their colors range from silver white, often tinged with yellow, steel gray and to the nearly black of petzite and nagyagite. Crystals are less dull in lustre. The streak is like the color.

|                               | Calaverite            | Sylvanite               | Krennerite               | Petzite                        | Nagyagite       |
|-------------------------------|-----------------------|-------------------------|--------------------------|--------------------------------|-----------------|
| <i>Hardness</i> .....         | 2.5                   | 1.5 to 2                | —                        | 2.5 to 3                       | 1 to 1.5        |
| <i>Specific gravity</i> ..... | 9.04                  | 7.9 to 8.3              | 8.35                     | 8.72 to 9.02                   | 6.85 to 7.2     |
| <i>Color</i> .....            | pale bronze<br>yellow | Steel gray<br>to silver | Silver to<br>pale yellow | Steel gray<br>to<br>iron black | nearly<br>black |

**BEFORE BLOWPIPE, ETC.**—On charcoal fuse (krennerite is said to decrepitate) to a gray button which after long heating yields a light yellow bead of gold alloyed with silver which is soluble in aqua regia with a curd-like white precipitate, and in the case of nagyagite there will be some yellow sublimate.

Rich powdered material (or the sublimate) placed on white porcelain touching a drop of hot concentrated, imparts a violet color to the acid.

In the open tube yield white sublimates which wholly or in part melt to clear transparent drops. Soluble in nitric acid.

**REMARKS.**—As described, p. 395, gold tellurides occur chiefly in the "young" veins. Calaverite is the most common, both at Kalgoorlie where it occurs massive, and at Cripple Creek, where it is often in complex crystals. Sylvanite is from Hungary, Colorado, California and Oregon. Petzite was in important quantities at the Bassick Mine, Colorado, and Hungary, and nagyagite in the Hungarian mines. Other localities are Calaveras and El Dorado Co., Colorado, Baker Co., Oregon; Kings Mt. Mine, North Carolina.

### THE PLATINUM GROUP.

The minerals described are:

|                           |                   |                   |           |
|---------------------------|-------------------|-------------------|-----------|
| <i>Platinum</i>           | <i>Platinum</i>   | Pt                | Isometric |
|                           | <i>Sperrylite</i> | PtAs <sub>2</sub> | Isometric |
| <i>Iridium and Osmium</i> | <i>Iridium</i>    | Ir Pt             | Isometric |
|                           | <i>Iridosmine</i> | (Ir.Os)           | Hexagonal |
| <i>Palladium</i>          | <i>Palladium</i>  | Pd                | Isometric |

**Tests.\***—Platinum will stay in the pan with gold and will not amalgamate with mercury alone but will float on the surface. If

\* For description of methods of determining the metals of the platinum group, see papers by A. M. Smoot and Martin Schwitter. *Eng. and Min. Journ.*, Vol. 99,

sodium is added it will amalgamate and can later be set free by shaking up with water until all sodium is converted into sodium hydroxide.

#### ECONOMIC IMPORTANCE.

The world's production\* of these metals in 1914 and 1915 is estimated in troy ounces as follows:

| Crude Platinum. —        | 1914.   | 1915.   |
|--------------------------|---------|---------|
| Russia . . . . .         | 241,200 | 124,000 |
| Colombia . . . . .       | 17,500  | 18,000  |
| United States . . . . .  | 570     | 742     |
| Canada . . . . .         | 30      | 100     |
| Crude Iridosmine.        |         |         |
| Tasmania and N. S. Wales | 1,248   | 303     |
|                          | 260,548 | 143,145 |

In addition to this there are considerable† quantities recovered in the refining of blister copper from ores in the Great Basin, Rocky Mountains, California, and Alaska, copper regions there in 1915 amounted to about 8,500 ounces troy (Platinum 6,495, Platladium 1,541, Iridosmine 355, Iridium 274).

#### The Uses.

*Platinum.*—Purified platinum is largely used in laboratory apparatus, dentistry and jewelry. An amount estimated‡ at 43,888 oz. in the U. S. is in use as a catalyzer in making fuming sulphuric acid.

The so-called contact mass consists of asbestos or magnesium sulphate soaked in a solution containing platinic chloride and then heated.

The metals, tungsten and molybdenum, have replaced platinum to a great extent in incandescent lamps, spark plug points and wires for the dental industry and the improvements in platinum plating have lessened the quantities used in jewelry.

Minor uses are in photography for platinotype prints, in the so-called "oxidizing of silver," and in the balance wheels of non-magnetic watches.

*Iridium.*—Platinum iridium alloys, which are harder and more

p. 700-701, and Vol. 97, p. 1249, reprinted in Mineral Resources U. S., 1914, pp. 347. and 349.

\* From *Mineral Production U. S.*, 1915, p. 140.

† *Mineral Production U. S.*, 1915, p. 139.

‡ *Ibid.*, 150.

resistant to acids than platinum, are used for pointing gold pens, surgical instruments, thermo couples, draw-plates for gold and silver wire, knife edges in delicate balances, and for standard weights and measures. The oxide is used in porcelain painting. A process of iridium plating also exists.

*Osmium*.—Formerly used in filaments of electric lamps, but has been replaced by tungsten. A very little is used in medicine and dyeing and as a stain in microscopy.

*Palladium* is used in dental alloys as a substitute for gold as a catalyzer, in soldering and whitening platinum and in coating surfaces such as silver reflectors of searchlights, and graduated circles of scientific instruments.

*Rhodium\** is used in making crucibles, dishes, thermo-couples, and as a catalyst.

No mineral chiefly rhodium has been found. The metal is, however, a noticeable constituent of the minerals of the platinum group. In 48 analyses of platinum it is recorded in 45, ranging from 11.07 to 0.29 per cent. In 12 analyses of Iridosmine it ranges from 12.30 to 0.50 per cent. In the Canadian sperrylite there is 0.72. In the Brazilian iridium 6.86 per cent.

Platinum, as it occurs in nature, is always alloyed with iron and other metals, from which it must be separated before it possesses the peculiar properties which make it valuable. The native mineral is first treated with dilute aqua regia, which dissolves out any iron, gold or copper. Then concentrated aqua regia is added to the residue, and the platinum and a small amount of iridium are brought into solution. After evaporation of the excess of acid, ammonium chloride is added, the ammonium-platinic chloride being formed and also a small amount of the iridium salt. This precipitate, on being heated, leaves the metal, which consists almost wholly of platinum, but also carries a small amount of iridium. The metals can be further separated, but for many purposes this alloy is preferable to the pure platinum.

The mother liquor from the platino chloride after the precipitation of the platinum contains the rhodium and palladium from which the palladium is precipitated by potassium cyanide, and the rhodium by iron and elaborate subsequent treatment.

The insoluble residue from the crude ore contains most of the iridium and osmium which are recovered by fusion with zinc or lead and later removal of these metals by volatilization or solution.



The residue may then be roasted to distill off osmium tetroxide or boiled in nitric acid to dissolve the iridium.

#### FORMATION AND OCCURRENCE OF THE PLATINUM GROUP MINERALS.

The metals are found in minute amounts in rocks, chiefly composed of chrysolite or its alteration, serpentine, as in the peridotites of Urals, Sierra Nevada, and Coast Ranges, the dunite of Tulameen River, B. C., and the serpentine of Italy and Asia Minor.

**Magmatic Segregations** occur in the nickel pyrrhotite deposits of Sudbury, Ontario, and Norway.\*

#### Veins and Replacements.

Platinum has been detected in quartz veins,\* first at Antioquia, Colombia, later at several American localities. At the Boss mine,† Yellow Pine District, Clark County, Nevada, a quartz mass replacing dolomite and containing "shoots" of chrysocolla, etc., and others of fine quartzose ore containing *plumbojarosite*, which in turn contains *gold*, *platinum* and *palladium*. The ore averages per ton 3.46 oz. gold, 6.4 silver, 0.7 platinum, 3.68 palladium. At the Rambler Mine, Wyoming, as an arsenical compound of platinum and palladium in *covellite*.

#### Sediments.

In marine sediments overlying basal granites east of Cologne, Germany, in quantities varying from a trace to one ounce per ton.

#### Placers or Gravels.

The economically important occurrences are gravels or placers near areas of decomposed chrysolite rocks or in rivers flowing from such areas.

*Choco, Colombia.*—Platinum was discovered in 1755 in the gold-bearing sands of Pinto River, Choco, Colombia. It is still obtained in important quantities from the Pacific coast area between the Cauco and Atrato Rivers.

*Urals.*—The most important platinum placers of the world are near Nizhni Tagilsk on the European slope of the Urals and Goroblagodatsk on the Asiatic slope. A third smaller district is also worked. The mineral is associated with iridosmine and chromite. These districts have supplied the world but the output

\* Beyschlag, Vogt & Krusch (Truscott), 1215.

† Mineral Production U. S., 1914, p. 339.

is steadily diminishing and the average yield is now only  $1/20$  oz. per ton gravel instead of  $1/2$  oz. The Urals gravels are sometimes changed to conglomerate.

*Bald Hills, Tasmania*, yields iridosmine from placers and it is also found in place in veins of chalcedony and opal in serpentine.

The iridosmine is sometimes coated with iron oxide, at other times enclosed in chromite. It contains hardly any platinum.

### PLATINUM.—Native Platinum.

**COMPOSITION.**—Pt(Fe), usually with small quantities of Rh, Ir, Pd, Os, Cu, and nearly always with Fe even as high as one-sixth of the whole.

**GENERAL DESCRIPTION.**—A malleable, steel-gray to white metal, occurring in small grains and nuggets in alluvial sands. Very rarely in small cubes.

**Physical Characters.** H., 4 to 4.5. Sp. gr., 14 to 19.

LUSTRE, metallic.

OPAQUE.

STREAK, steel gray.

TENACITY, malleable.

COLOR, light steel gray.

Often magnetic.

**BEFORE BLOWPIPE, ETC.**—Infusible and unaffected by fluxes or any single acid. Soluble in aqua regia.

**SIMILAR SPECIES.**—Heavier than silver and not soluble in nitric acid.

**REMARKS.**—Occurs as stated, p. 404, and also in many gold placers of California and Oregon and sometimes in the beach sands.

In Canada it is found in Beauce County, Quebec, and Tulameen River, British Columbia. In Minas Geraes, Brazil in gold sand, with palladium, and iridosmine. It is also found in gold placers in Borneo, New Zealand and New South Wales.

### SPERRYLITE.

**COMPOSITION.**—PtAs<sub>2</sub> (Pt, 52.57; As, 43.5 per cent.) with some replacement of platinum by rhodium and palladium.

**GENERAL DESCRIPTION.**—A tin-white, brittle and opaque mineral of metallic lustre found in minute cubes and octahedra and in grains. H., 6 to 7. Sp. gr., 10.60.

**BEFORE BLOWPIPE, ETC.**—If rapidly heated in the open tube fuses easily with a loss of part of the arsenic. Instantly fused if dropped on red hot platinum. In closed tube unchanged. Slowly soluble in concentrated hydrochloric acid.

**REMARKS.**—Occurs in small amount with the nickel ores of Sudbury, Ontario, and in the chalcopyrite and covellite of the Rambler, Mine, Wyoming. Has been found in Macon County, N. C., with gold and rhodolite and is believed to exist in the platinum-bearing dikes of Bunkerville, Nevada.

**IRIDIUM (PLATIN-IRIDIUM).**

**COMPOSITION.**—Iridium alloyed with platinum, palladium, rhodium, little if any osmium.

**GENERAL DESCRIPTION.**—Angular and rounded, slightly malleable grains in platinum deposits with specific gravity and melting point much higher than platinum. Color, silver white with tinge of yellow. H., 6 to 7. Sp. gr., 22.6 to 22.8.

**BEFORE BLOWPIPE, ETC.**—Infusible and insoluble in all acids. Attacked by chlorine gas.

**REMARKS.**—The rarest of platinum ores. Found in the Ural platinum deposits, the gold sands of Ava, Burmah. It is reported also from Brazil and Tasmania.

**IRIDOSMINE.**

**COMPOSITION.**—(Ir.Os), sometimes with Rh, Pt, etc.

**GENERAL DESCRIPTION.**—A tin-white or gray, metallic mineral, very hard and heavy, and occurring in irregular, flattened grains and hexagonal plates.

**PHYSICAL CHARACTERS.**—Opaque. Lustre metallic. Color and streak, tin white or gray. H., 6 to 7. Sp. gr., 19.3 to 21.1. Rather brittle.

**BEFORE BLOWPIPE, ETC.**—Infusible. May yield unpleasant, pungent odor. Insoluble in acids.

**REMARKS.**—Iridosmine is found with platinum in the Urals; Choco, Colombia; Bingera, New South Wales; Victoria; American River, California; Gunung Ratus, Borneo; and Beauce County, Quebec.

**PALLADIUM.**

**COMPOSITION.**—Palladium with a little platinum and iridium.

**GENERAL DESCRIPTION.**—Malleable grains, sometimes radial fibrous and minute octahedra of light steel-gray color. H., 4 to 5. Sp. gr., 11.3 to 11.8.

**BEFORE BLOWPIPE, ETC.**—Melts more easily than the other platinum metals. Heated in air becomes bluish on surface. Soluble in nitric acid to brownish-red solution. Also soluble in concentrated hydrochloric or sulphuric acids.

**REMARKS.**—Found first in the platinum from Choco, Colombia, later in the gold sands of Cornego, Minas, Geraes, Brazil; and is reported from the Antilles and Urals. Palladium from Tilkerode, Harz, is called "Allopalladium" and considered to be hexagonal.

Palladium occurs either as metal or arsenide in the copper nickel ores of Sudbury and the slimes from these ores are the chief commercial source.

**THE ALUMINUM MINERALS.**

The minerals described are :

|                   |                  |  |              |
|-------------------|------------------|--|--------------|
| <i>Fluoride</i>   | <b>Cryolite</b>  | $\text{AlNa}_3\text{F}_6$  | Triclinic    |
| <i>Oxide</i>      | <b>Corundum</b>  | $\text{Al}_2\text{O}_3$  | Hexagonal    |
| <i>Hydroxides</i> | <b>Bauxite</b>   | $\text{Al}_2\text{O}(\text{OH})_3$                               |              |
|                   | <b>Diaspore</b>  | $\text{AlO}(\text{OH})$  | Orthorhombic |
|                   | <b>Gibbsite</b>  | $\text{Al}(\text{OH})_3$   | Monoclinic   |
| <i>Sulphates</i>  | <b>Alunogen</b>  | $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$          | Monoclinic   |
|                   | <b>Aluminite</b> | $(\text{AlO})_2\text{SO}_4 \cdot 9\text{H}_2\text{O}$            | Monoclinic   |
|                   | <b>Alunite</b>   | $\text{K}(\text{AlOH})_2(\text{SO}_4) \cdot 3\text{H}_2\text{O}$ | Rhombohedral |

Aluminum is also present in many silicates, the greater portion being in the feldspars, feldspathoids, micas, aluminous pyroxenes and amphiboles, garnet and the clays. The phosphates wavellite and turquois are described elsewhere.

#### ECONOMIC IMPORTANCE.

The ores of aluminum are the hydroxides, bauxite, diaspore, gibbsite, and the fluoride, cryolite. A probable ore of the future is alunite.

*Bauxite* to the amount of 297,041 long tons was produced\* in 1915, Arkansas and Tennessee furnishing 272,033 Georgia and Alabama the rest.

*Cryolite* to the amount of about 4,612 tons was imported into the United States from Greenland in 1914, and is used as a flux in the manufacture of aluminum.

Alunite has been and still is used for the manufacture of alum and in connection with the first shipment† of 28 tons of potassium sulphate in 1915 from the treatment of Marysvale, Utah, alunite, the use of the residual "filter cake" which is about 65 per cent  $\text{Al}_2\text{O}_3$  for the manufacture of aluminum becomes very probable.

The formerly important industry in manufacturing alum from the alum shales so common in the brown coal formations is of relatively small importance; the soluble sulphates were the result of the action of decomposing pyrite on the shales.

In 1915 this country produced|| 49,903 short tons of aluminum, 24,915 of alum and 169,153 of aluminum sulphate.

The world's production of aluminum in 1914 is estimated¶ at 86,390 metric tons, about one-half from the U. S.

|                    |        |                      |       |
|--------------------|--------|----------------------|-------|
| United States..... | 42,210 | Canada.....          | 6,820 |
| France.....        | 12,000 | Austria-Hungary..... | 4,000 |
| Switzerland.....   | 10,000 | Norway.....          | 2,500 |
| Great Britain..... | 8,000  | Italy.....           | 800   |

\* Mineral Resources U. S., 1914, p. 183.

† Mineral Resources U. S., 1915, p. 159.

‡ *Ibid.*, 1915, p. 129.

§ *Ibid.*, p. 111.

|| Min. Resources U. S., 1915, p. 167 and 173.

¶ *Mineral Industry*, 1914, p. 189.

### **The Metallurgy and Uses of Aluminum.**

The ore is heated with sodium carbonate to low redness, in order to produce sodium aluminate without rendering the silica or iron soluble. On dissolving out the sodium aluminate with water and passing carbon dioxide through the solution, aluminum hydroxide is formed, which yields the oxide when heated. By this mode of procedure most of the iron and silicon are separated, which would otherwise be reduced by the current and alloyed with the aluminum. In a more recent process the impurities in the bauxite are removed by fusing the ore with carbon in an electric furnace whereby iron, silicon and titanium are reduced or converted into carbides and separate on top of the aluminum oxide formed.

For the production of the pure metal the oxide is decomposed by electrolysis in a fused solvent which protects the metal from contact with oxygen. The Hall and Heroult processes consist in the electrolysis of the oxide in a fused bath of cryolite or the mixed fluorides of sodium and aluminum. The Hall process is carried on in iron tanks, the bottom and sides of which are thickly lined with carbon. The tanks serve as the negative electrodes and are filled with the cryolite flux, to which a little fluorite is added. The positive electrodes are carbon cylinders, which dip into the electrolyte.

The cylinders are first lowered until they touch the bottom of the tank, and the ground cryolite is melted as a result of the poor contact. The cylinders are then raised, and the current thenceforth passes through the melted liquid. The alumina is now added, and is immediately dissolved by the flux and decomposed by the current. The metal settles at the bottom of the bath, while the oxygen combines with the carbon of the anode and escapes as carbon dioxide. The metal is removed from time to time, alumina is again added and thus the operation is continuous.

Aluminum is used where lightness, strength and non-corrosiveness are desirable, *e. g.*, in some scientific apparatus, in fancy articles, to a limited extent in cooking utensils. It is replacing sheet copper and zinc, and is used as bronze powder and aluminum leaf for silvering letters and signs. It is of growing importance as a substitute for stone and zinc in lithographing and is used in large quantities for electrical conductors. Aluminum is especially sonorous and is now used in the Austrian army for drums, and the

substitution of aluminum for brass in the other band instruments is being tried.

Two interesting uses of aluminum in metallurgy are: The welding of wrought iron pipes, rails and steel castings, in place, by the heat developed by oxidation of powdered aluminum mixed with oxide of iron (Thermite); the prevention of blow-holes in castings of steel, copper or zinc by the addition of less than one per cent. of aluminum to the melted metal.

The alloys of aluminum are extensively used, especially the alloy with copper, known as aluminum bronze, which contains usually as much as ten per cent. of aluminum. It is extremely tough and is extensively applied in machinery, especially mine machinery, engine castings, etc. The alloys with zinc, nickel and tin are also of importance and to some extent are replacing brass. The alloys with zinc are malleable and ductile and when chilled possess a high tensile strength. Alloys with tungsten are also growing in importance.

The great demand of 1914 is said to be due to its use in the explosive "ammonal," a mixture of nitrate of ammonia and powdered aluminum. The burning of the aluminum expands the explosive gases.

Bauxite with a melting point of  $1,820^{\circ}$  C. is not only the source of most of the aluminum of commerce but is also used in the production of alum and other compounds of aluminum used extensively in dyeing and calico printing. It is also made into bricks for lining open hearth steel furnaces, copper converters and Portland cement kilns and by fusion in the electric furnace it is made into "Alundum" much used in grinding steel.

*Cryolite* is used in the making of enamels for kitchen ware and opalescent glasses.

The uses of corundum and other described species will be mentioned under the species.

#### THE FORMATION AND OCCURRENCE OF ALUMINUM MINERALS.

##### In Pegmatites.

*Corundum*—in syenites and nepheline syenites of Ontario, Canada, as 15 to 20 per cent. of their composition, also in syenite of Gallatin County, Montana, and anorthosite of India.

*Cryolite* at Arksutford, Greenland, as central part of coarse granitic pegmatite carrying the common sulphides and marginally these with wolframite, cassiterite, columbite and molybdenite. An adjoining pegmatite has the same species but no cryolite.

#### **Magmatic Segregation.**

Corundum will crystallize directly from magmas such as nepheline syenite exceptionally *high* in alumina and from peridotite or other magnesian rocks exceptionally low in alumina.\* In the latter by segregation economic deposits may result as in the norite at Peekskill, N. Y., the amphibolites of Chester, Mass., and the "segregation lumps" near Mts. Painter and Pitt, South Australia.

#### **In Contacts.**

*Bauxite* is regarded by some authorities\* as "usually alterations of limestone in contact zones."

*Corundum*.—In limestone as with the rubies of Burma and the emery of Naxos, Greece, and the adjoining mainland of Asia Minor. The "contact veins"† between peridotite and schists and their alterations, the amphiboles and chlorite schists, along the Appalachian range from Alabama to Massachusetts, especially in North Carolina, and Georgia.

#### **Formed by Exhalations and Acid Solutions.**

*Alunite* is formed by action of sulphurous vapors on trachyte or other young, porous, orthoclase-bearing rocks as at Rosita Hills, Colorado; Marysvale, Utah; Goldfields, Nevada, where the altered rocks enclose the gold deposits; Cartagena and Mazarron, Spain, with young gold-silver veins; Tolfa, Rome; Musaz, Hungary; Bullah Delah, New South Wales; and many other localities.

A large deposit at Kyoquot Sound, Vancouver Island, is said‡ to be "of the sodic variety."

*Alunogen*.—A large deposit on Gila River near Silver City, New Mexico, occupies the crater of an extinct volcano and is due to action of vapors and surface waters on the andesite breccia.§

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\* Beysschlag, Vogt & Krusch (Truscott), p. 103.

† Merrill's "Non-metallic Minerals," p. 75.

‡ *Mineral Industry*, 1914, p. 40.

§ Bulletin No. 315, U. S. Geol. Survey.

**Sedimentary.**

The usual aluminous products of rock decay in temperate regions are the hydrous silicates known as clays; the hydroxides are rarely found in soil analyses. In tropical or sub-tropical regions they are frequently found as laterite\* and bauxite and it is probable that the deposits found in temperate climates were formed under different climatic conditions.†

The methods of formation are not settled nor are all deposits genetically alike; some authorities‡ regard the bauxite (and dias-pore) as alterations of limestone in contact zones and to some small extent decomposition products of basic eruptives, especially basalt. According to Lindgren, the Gila River bauxite and certain Hawaiian soils owe the de-silication of their clay to sulphuric acid and sodium salts,§ while for other regions quite different origins are claimed.

*Arkansas.*||—In Pulaski and Saline Counties as superficial 10 ft. deep beds over considerable areas. They rest on nepheline syenite and it is thought that this may have been covered by salt or alkaline water, perhaps supplied by hot springs and that some of the dissolved  $Al_2O_3$  was precipitated as colloid.

*Georgia and Alabama.*—Pockets and irregular masses or curved strata with clay and limonite in the residual clay overlying dolomite, occasionally associated gibbsite and halloysite. Below the dolomite is shale rich in  $Al_2O_3$  and pyrite. Many faults. It is thought that atmospheric water percolating through the shale decomposed the pyrite, and the resulting acid solutions decomposed the clay forming sulphate, which dissolved the dolomite and was precipitated by it.

*France.*—First at Les Vaux near Marseilles, then in a band almost parallel to the Mediterranean in Provence and Lanquedoc (Var, Herault, etc.), in pockets in corroded limestone. Attributed to ascending springs and precipitation by the limestone.

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\* Bauxite and laterite are rocks rather than minerals, laterite being hydroxides with much iron and clay, transported and spread out products of decomposition of aluminous rocks; bauxites, are products formed *in situ* from colloidal material.

† Lindgren, *Mineral Deposits*, p. 330.

‡ Beyschlag, Vogt & Krusch, p. 103.

§ *Mineral Deposits*, p. 328.

|| Lindgren, *Mineral Deposits*, p. 329.



**CRYOLITE.—Eisstein.**

**COMPOSITION.**— $\text{AlNa}_3\text{F}_6$ . (Al 12.8, Na 32.8, F 54.4 per cent.).

**GENERAL DESCRIPTION.**—Soft, translucent, snow-white to colorless masses, resembling spermaceti or white wax in appearance. Occasionally with groups of triclinic crystals so slightly inclined as to closely approach cubes and cubic octahedrons in angle and form.

**Physical Characters.** H., 2.5. Sp. gr., 2.95 to 3.

**LUSTRE,** vitreous or wax-like. **TRANSLUCENT** or transparent.

**STREAK,** white.

**TENACITY,** brittle.

**COLOR.**—Colorless, white, brown.

**CLEAVAGE.**—Basal and prismatic, angles near  $90^\circ$ .

**BEFORE BLOWPIPE, ETC.**—Fuses very easily, with strong yellow coloration of the flame, to a clear globule, opaque when cold. With cobalt solution, becomes deep blue. In closed tube, yields acrid fumes, which attack and etch the glass. Soluble in acid without effervescence.

**SIMILAR SPECIES.**—Characterized by its easy fusibility, and fumes which attack glass.

**REMARKS.**—Found at Ivigtut, Greenland, as described on p. 410, and in smaller amounts in the Ilmen Mts., Pikes Peak, Colorado and Yellowstone Park.

**CORUNDUM.—Sapphire, Ruby, Emery.**

**COMPOSITION.**— $\text{Al}_2\text{O}_3$ . (Al 52.9, O 47.1 per cent.).

**GENERAL DESCRIPTION.**—With the exception of the diamond, the hardest of all minerals. Occurs in three great varieties, which are most conveniently described separately.

FIG. 409.

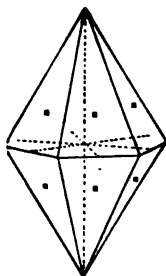


FIG. 410.

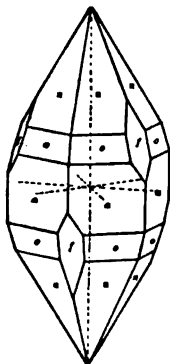
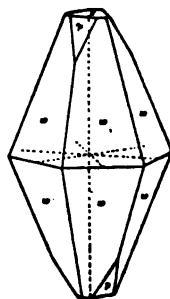


FIG. 411.



**CRYSTALLIZATION.**—Hexagonal. Scalenohedral class, p. 48. Axis  $c = 1.363$ . Crystals often rough and rounded. Second order pyramids predominate as  $n$ ,  $o$ , and  $w$  intersecting the vertical axis at respectively  $\frac{1}{2}c$ ,  $\frac{1}{3}c$  and  $2c$ . Unit rhombohedron  $p$  and the more acute form  $f(2c)$  also occur. Supplement angles  $nn = 51^\circ 58'$ ;  $oo = 57^\circ 38'$ ;  $ww = 56^\circ$ .

Optically —, with rather strong refraction but weak double refraction ( $a = 1.759$ ;  $\gamma = 1.767$ ).

**Physical Characters.** H., 9. Sp. gr., 3.95 to 4.11.

LUSTRE, vitreous or adamantine. TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle to tough.

COLOR, blue, red, green, yellow, black, brown or white.

CLEAVAGE, rhombohedral, angle of  $86^\circ 4'$ .

**BEFORE BLOWPIPE, ETC.**—Infusible and unaltered, alone or with soda, or sometimes improved in color. Becomes blue with cobalt solution at high heat. Insoluble in acids and only slowly soluble in borax or salt of phosphorus.

#### Varieties.

*Sapphire or Ruby.*—Transparent to translucent, sometimes in crystals and of fine colors—blues, reds, greens, yellows, etc.

*Adamantine Spar or Corundum.*—Coarse crystals or masses, with cleavage  $86^\circ$  and parting  $57^\circ$ , or granular, slightly translucent, and usually in some blue, gray, brown or black color.

*Emery.*—Opaque, granular corundum, intimately mixed with hematite or magnetite, usually dark-gray or black in color.

**REMARKS.**—The occurrence of corundum as direct crystallization from magma and of deposits in pegmatites and as segregations, and contact veins have been pointed out, pp. 409, 410. The usual connection is with peridotites gabbros norites and similar rocks and their alterations carrying chrysolite or in syenitic rocks, less frequently in limestones and dolomites. Prominent localities have already been mentioned.

**USES.**—The use as gems is discussed later. Adamantine spar and emery are important abrasive materials, and thousands of tons are used in grinding and polishing glass, gems and metals.

#### BAUXITE. Laterite.

**COMPOSITION.**— $*Al_2O_3, 2H_2O$ , this fitting fairly the French deposits, whereas the Georgia deposits are closely gibbsite,  $Al_2O_3$ ,

\* Beyschlag, Vogt & Krusch (Truscott), p. 359.

$3\text{H}_2\text{O}$ , and the hydroxide of metasomatic\* origin is stated to be chiefly diaspore,  $\text{Al}_2\text{O}_3$ ,  $\text{H}_2\text{O}$ . Bauxite is rather a rock of colloidal origin than a mineral and may be regarded as a mixture of diaspore and gibbsite.  $\text{TiO}_2$  is present, up to 4 per cent. and sometimes vanadium.

**GENERAL DESCRIPTION.**—Usually pisolitic masses or porous to compact, earthy and clay-like. Color, white, gray, cream, or, if ferruginous, will be yellow, brown or red.

FIG. 413.



Bauxite, Bartow County, Ga. U. S. National Museum.

**Physical Characters.** H., 1 to 3. Sp. gr., 2.4 to 2.5.

LUSTRE, dull or earthy.

OPAQUE.

STREAK, like color.

TENACITY, brittle.

COLOR, white, red, yellow, brown or black.

**BEFORE BLOWPIPE, ETC.**—Infusible. Becomes deep blue with cobalt solution, and may become magnetic in reducing flame. In closed tube yields water at high heat. Soluble with difficulty in hydrochloric acid.

**REMARKS.**—In addition to the deposits mentioned on p. 411, deposits of less moment occur in Carniola, Austria; Italy, Ireland, and the Pyrenees. Extensive "laterite" deposits occur in India and elsewhere, which usually carry much iron and clay.

### DIASPORE.

COMPOSITION.— $\text{AlO}(\text{OH})$ , ( $\text{Al}_2\text{O}_3$  85.1,  $\text{H}_2\text{O}$  14.9 per cent.).

GENERAL DESCRIPTION.—Thin, flat, orthorhombic prisms, foliated masses and thin scales. When pure, it is transparent and white or pinkish in color. When impure, it is often brown.

PHYSICAL CHARACTERS.—Transparent to nearly opaque. Lustre, pearly and vitreous. Color, gray, white, pink, yellow, brown. Streak, white. H., 6.5 to 7. Sp. gr., 3.3 to 3.5. Very brittle. Cleaves into plates.

BEFORE BLOWPIPE, ETC.—Infusible. Usually decrepitates. With cobalt solution, becomes deep blue. In closed tube, yields water at high heat. Insoluble in acids.

SIMILAR SPECIES.—Distinguished by its hardness, cleavage and decrepitation.

REMARKS.—Occurs with corundum and its associates at Chester, Mass., also with bauxite and laterite. At Remez, Hungary, occurs at contact with limestone.

### GIBBSITE.

COMPOSITION.— $\text{Al}(\text{OH})_3$ , ( $\text{Al}_2\text{O}_3$  65.4,  $\text{H}_2\text{O}$  34.6 per cent.).

GENERAL DESCRIPTION.—Best known as a white or nearly white mineral, usually occurring in small stalactites (Fig. 205) or thin smooth crusts, with fibrous internal structure. Rarely in small monoclinic crystals. The great deposits of "bauxite" in Georgia are, however, chiefly gibbsite.

PHYSICAL CHARACTERS.—Translucent. Lustre, faint vitreous. Color, white greenish, reddish, yellow. Streak, white. H., 2.5 to 3.5. Sp. gr., 2.38.

BEFORE BLOWPIPE, ETC.—Infusible, exfoliates, glows and becomes white. With cobalt solution becomes deep blue. In closed tube yields water. Soluble in <sup>concentrated</sup> ~~hydro-~~chloric or sulphuric acid.

REMARKS.—Rare as pure material, plentiful in bauxite and laterite. The pure mineral is found with corundum in Asia Minor, in *elaeolite* syenite in Norway and in small quantity at Richmond and Lenox, Mass., and Dutchess and Orange counties, N. Y.

### ALUMINITE.

COMPOSITION. —  $(\text{AlO})_2\text{SO}_4 \cdot 9\text{H}_2\text{O}$ , ( $\text{Al}_2\text{O}_3$  29.6,  $\text{SO}_3$  23.3,  $\text{H}_2\text{O}$  47.1 per cent.).

GENERAL DESCRIPTION.—Usually found in white rounded or irregular masses of chalk-like texture and peculiar harsh feeling.

PHYSICAL CHARACTERS.—Opaque. Lustre, dull or earthy. Color and streak, white. H., 1 to 2. Sp. gr., 1.66. Meagre to the touch and adheres to the tongue.

BEFORE BLOWPIPE, ETC.—Infusible. In closed tube yields much acid water. With cobalt solution becomes deep blue. Easily soluble in acid.

REMARKS.—Found in clay beds at Halle, Germany, and at Brighton, England, filling a three-foot cleft in the chalk. Other localities in France and Bohemia.

### ALUNOGEN.

COMPOSITION.— $\text{Al}_2(\text{SO}_4)_3 + 18\text{H}_2\text{O}$ , ( $\text{Al}_2\text{O}_3$  15.3,  $\text{SO}_3$  36.0,  $\text{H}_2\text{O}$  48.7 per cent.).

GENERAL DESCRIPTION.—A delicate fibrous crust of white or yellow color. Sometimes massive. Tastes like alum.

PHYSICAL CHARACTERS.—Translucent. Lustre, vitreous or silky. Color, white yellowish or reddish. Streak, white. H., 1.5 to 2. Sp. gr., 1.6 to 1.8. Taste, like alum.

**BEFORE BLOWPIPE, ETC.**—Melts in its own water of crystallization, but becomes infusible. It is colored deep blue by cobalt solution. In closed tube yields much acid water. Easily soluble in water.

**REMARKS.**—Formed by action of sulphuric acid of decomposing sulphides upon aluminous shales. Also formed during volcanic action.

The large deposit near Silver City, New Mexico, has been mentioned on p. 410.

#### **ALUNITE. — Alum Stone.**

**COMPOSITION.** —  $K(AlOH)_3(SO_4)_2 + 3 H_2O$ , ( $Al_2O_3$  37.0,  $K_2O$  11.4,  $SO_3$  38.6,  $H_2O$  13 per cent.).

**GENERAL DESCRIPTION.**—Occurs fibrous and in tabular to nearly cubic rhombohedral crystals, or so intermixed with a siliceous material as to form a hard granular and nearly white rock.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 2.58 to 2.75.

LUSTRE, vitreous.

TRANSPARENT to nearly opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white, grayish or reddish.

**BEFORE BLOWPIPE, ETC.**—Infusible and decrepitates. With cobalt solution becomes deep blue. With soda infusible, but the mass will stain silver. In closed tube yields water at a red heat. Imperfectly soluble in hydrochloric or sulphuric acid.

The specimen may be boiled in water or acid to remove soluble sulphates, then heated to redness, again boiled in water, the clear liquid tested by addition of  $BaCl_2$ .

**REMARKS.**—The formation and principal occurrences are stated on p. 410, and its uses on p. 418.

## CHAPTER XIX.

### MINERALS IMPORTANT IN THE INDUSTRIES AND NOT ALREADY DESCRIBED.

In this division the minerals are rather of chemical than of metallurgical importance, although the line is difficult to draw. So far as possible the minerals used as sources of compounds of a particular element are grouped together.

It is to be noted that the minerals are for the most part products of weathering of the rocks and deposited from weathering solutions, rather than separations from magma or magmatic waters.

#### THE POTASSIUM MINERALS.

The minerals described are :

|                  |                   |   |              |
|------------------|-------------------|---|--------------|
| <i>Chlorides</i> | <i>Sylvite</i>    | KCl   | Isometric    |
|                  | <i>Carnallite</i> | KCl.MgCl <sub>2</sub> .6H <sub>2</sub> O                | Orthorhombic |
|                  | <i>Kainite</i>    | KCl.MgSO <sub>4</sub> .3H <sub>2</sub> O                | Monoclinic   |
| <i>Sulphates</i> | <i>Kalinite</i>   | K Al(SO <sub>4</sub> ) <sub>2</sub> .12H <sub>2</sub> O | Isometric    |
| <i>Nitrate</i>   | <i>Nitre</i>      | KNO <sub>3</sub>  | Orthorhombic |

In addition to these, potassium is a constituent of many silicates, such as orthoclase, muscovite and leucite. It is also found in solution in many brines.

#### ECONOMIC IMPORTANCE.

Potash salts to the amount of 306,000 tons were imported in 1913. In 1914 this had diminished to 243,000 and in 1915 to 85,000 tons\* valued at \$3,765,224.

The imports in pounds of different salts were:

|                                     | 1914.       | 1915.       |
|-------------------------------------|-------------|-------------|
| Carbonate of, crude.....            | 9,326,899   | 5,386,719   |
| Caustic, not including refined..... | 7,284,176   | 2,032,319   |
| Cyanide of.....                     | 417,139     | 871,871     |
| Chloride of.....                    | 371,521,920 | 2,296,606   |
| Nitrate of, saltpeter, crude.....   | 2,230,528   | 6,855       |
| Sulphate of.....                    | 80,447,360  | 25,415,040  |
| All other.....                      | 14,590,437  | 7,502,806   |
| Total.....                          | 485,818,459 | 170,555,450 |

\* Mineral Industry of U. S., 1915, p. 96.

As one effect of the European war this country has been forced to search for and utilize other sources for potash than the Stassfurt salts and in 1915 potash salts to the value of \$342,000 were obtained\* from domestic sources, such as:

By-product potash from the cement manufacture.

Potassium sulphate from alunite of Maryvale, Utah.

Dried kelp.

By evaporation of water from Jesse Lake, Nebraska.

The uses† of the potassium salts and the quantities used are indicated by the importations for the month of February, 1914:

| Fertilizer salts:       |            | Other potash salts:    |           |
|-------------------------|------------|------------------------|-----------|
|                         | Long Tons. |                        | Pounds.   |
| Kainite.....            | 72,008     | Carbonate of potash..  | 1,674,685 |
| Manure salts.....       | 12,451     | Caustic potash.....    | 520,166   |
| Sulphate of potash..... | 5,098      | Nitrate of potash....  | 22,699    |
| Chloride of potash..... | 13,172     | Cyanide of potash....  | 5,641     |
|                         |            | Other potash salts.... | 638,112   |

The carbonate of potash is used in glass-making, the cyanide in metallurgy, the nitrate in explosives, the sulphate and the chloride in fertilizers. Other large amounts are used in making soap, matches, in photography and pharmacy.

While the search for the solid deposits similar to those of Stassfurt and for deposits of nitrate of commercial importance has not been successful other saline lakes‡ rich in potash salts are being equipped for extraction, such as Searles Lake, California; Owens Lake, California; Great Salt Lake, Utah.

*Alunite*, p. 416, has been successfully treated§ at Marysval, Utah. It is crushed, roasted, digested with water and potassium sulphate obtained. The filter cake is about 65 per cent.  $Al_2O_3$  and the  $K_2SO_4$  over 95 per cent. pure.

Methods have been described and patented for production of potassium salts from orthoclase, leucite and sericite or white muscovite. It is said the products are necessarily low grade.||

\* *Ibid.*, p. 95.

† *Ibid.*, p. 95.

‡ Mineral Resources, U. S., 1915, pp. 101-103.

§ *Ibid.*, p. 110.

|| *Ibid.*, p. 95.

**FORMATION AND OCCURRENCE.**

The crust of the earth contains, it is estimated, 2.33 per cent. of potassium, very largely in the great silicates, orthoclase, muscovite and leucite and in the products resulting from their decomposition. It is necessary to plant life and is present in all soils, being, as stated on p. 244, at the decomposition of the rocks carried off to a much less extent than sodium by the solutions, but adsorbed by colloidal matters in clay and soil and often recombined to sericite (white muscovite). The portion that does reach the sea is again lessened by seaweed and even in land-locked basins after the deposition of the less soluble calcium and sodium salts is rarely deposited but remains in the mother liquor or bitterns. Some Michigan brines contain up to 3 to 5 gm. per liter. One at Fairport Harbor, Ohio, ran 7.4 KCl.

Under the Ochsenius "bar" theory, p. 423, the dense solutions before the separation of the potassium and magnesium salts reach the bar level and the "bitterns" escape to the sea.

In rare instances, as at Stassfurt, Germany, p. 225, from peculiar geological conditions these residual salts (Abraumsalze) are deposited principally as carnallite and kainite, sylvite being subordinate.

Smaller deposits exist in Upper Alsace, Tyrol, Kalusz, Galicia, and India and valuable deposits have been found in mining salt near Suria, south of Cardona, near Barcelona, in northeastern Spain.

Nitre deposits are numerous but not generally large—an extensive layer exists in the soda nitre region of Tarapaca, Chili, and small deposits in Arizona, Idaho and elsewhere.

**SYLVITE.**

**COMPOSITION.**—KCl, (K 52.4 per cent.).

**GENERAL DESCRIPTION.**—Colorless, transparent cubes or white masses, which look like common salt and have somewhat similar taste. Absorbs moisture and becomes damp.

**PHYSICAL CHARACTERS.**—Transparent when pure. Lustre, vitreous. Color, colorless white, bluish, reddish. Streak, white. H., 2. Sp. gr., 1.97 to 1.99. Taste, like salt. Cleavage in cubes.

**BEFORE BLOWPIPE, ETC.**—Fuses very readily, coloring flame violet. If added to a salt of phosphorus and copper oxide bead, the flame is colored azure blue. Soluble in water and acids.



**CARNALLITE.**

COMPOSITION.— $\text{KCl} \cdot \text{MgCl}_2 + 6\text{H}_2\text{O}$  (K 14.1 per cent.).

GENERAL DESCRIPTION.—A massive and somewhat granular mineral occurring in beds or strata at the Stassfurt potash salts deposit of Germany. Seldom found in crystals.

PHYSICAL CHARACTERS.—Translucent to transparent. Lustre, sub-vitreous. Color, white, brownish and reddish. Streak, white. H., 1.  $G = 1.62$ . Taste, salty and bitter.

BEFORE BLOWPIPE, ETC.—Same as for sylvite. Very deliquescent.

USES.—Is the chief source of the manufactured potash salts of commerce which are so largely used as fertilizers. It is simply dissolved in water and the potassium chloride crystallized out at the proper temperature.

**KAINITE.**

COMPOSITION.— $\text{MgSO}_4 \cdot \text{KCl} + 3\text{H}_2\text{O}$ .

GENERAL DESCRIPTION.—White to dark red granular crusts with salty taste, also tabular and prismatic monoclinic crystals.

Physical Characters. H., 2.5–3. Sp. gr., 2.05–2.2.

LUSTRE, vitreous.

TRANSPARENT to translucent.

STREAK, colorless.

TASTE, salty and astringent.

COLOR, white to reddish white, and colorless.

BEFORE BLOWPIPE, ETC.—Easily fusible, coloring the flame violet. After fusion on charcoal in reducing flame the moistened mass will stain bright silver. Soluble in water.

**KALINITE.—Potash Alum.**

COMPOSITION.— $\text{KAl}(\text{SO}_4)_2 + 12\text{H}_2\text{O}$  (K<sub>2</sub>O 9.9, Al<sub>2</sub>O<sub>3</sub> 10.8, SO<sub>3</sub> 33.8, H<sub>2</sub>O 45.5 per cent.).

GENERAL DESCRIPTION.—Natural alum with the peculiar taste, occurring as a white efflorescence on argillaceous minerals. Usually fibrous, or as mealy crusts, or compact.

PHYSICAL CHARACTERS.—Transparent or translucent. Color, white. Lustre, vitreous. Streak, white. Taste, astringent. Tenacity, brittle. H., 2.5. Sp. gr., 1.75.

BEFORE BLOWPIPE, ETC.—On heating, becomes liquid, yields water, and finally swells to a white, spongy, easily-powdered mass, *which is infusible*, but colors the flame violet. With cobalt solution, becomes deep blue on heating. Soluble in water.

REMARKS.—A white efflorescence on pyritiferous clays or clay slates and a sublimation product of burning coal fields and volcanoes.

**NITRE.—Saltpetre.**

COMPOSITION.— $\text{KNO}_3$ , (K<sub>2</sub>O 46.5, N<sub>2</sub>O<sub>5</sub> 53.5 per cent.).

GENERAL DESCRIPTION.—White crusts, needle-like, orthorhombic crystals and silky tufts, occurring in limestone caverns or as incrustations upon the earth's surface or on walls, rocks, etc. Not altered by exposure.

**Physical Characters.** H., 2. Sp. gr., 2.09 to 2.14.

LUSTRE, vitreous.

TRANSLUCENT.

STREAK, white.

TENACITY, brittle.

COLOR, colorless, white, gray.

TASTE, salty and cooling.

**BEFORE BLOWPIPE, ETC.**—On charcoal fuses easily, deflagrates violently like gunpowder, colors the flame violet. Soluble in water.

**REMARKS.**—Occurs as an efflorescence in soils containing excrement as in India, Egypt, Algeria, Persia, Spain. Sometimes occurs lining the walls of caves in limestone as in Kentucky, Tennessee, France and Germany.

### THE SODIUM MINERALS.

The minerals described are :

|                  |                   |   |            |
|------------------|-------------------|---|------------|
| <i>Chloride</i>  | <b>Halite</b>     | NaCl  | Isometric  |
| <i>Sulphate</i>  | <b>Mirabilite</b> | $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$                     | Monoclinic |
| <i>Nitrate</i>   | <b>Soda Nitre</b> | $\text{NaNO}_3$   | Hexagonal  |
| <i>Carbonate</i> | <b>Trona</b>      | $\text{Na}_2\text{CO}_3 \cdot \text{HNaCO}_3 \cdot 2\text{H}_2\text{O}$ | Monoclinic |

Sodium is an important constituent in plagioclase nephelite, sodalite and other silicates, and in such minerals as cryolite, ulexite and borax.

### ECONOMIC IMPORTANCE.

The only sodium salt produced in quantity in the United States is halite, of which the production in 1915\* was 5,352,409 short tons produced by fourteen states, nearly half coming from Michigan and New York and about one fifth from Ohio, Kansas, Louisiana and California in the order named.

Mirabilite from Wyoming and the Great Salt Lake and trona from Nevada and California in comparatively small amounts are obtained.

Soda nitre was imported† in 1914 to the amount of 620,533 tons, as well as many manufactured salts. Those imported in excess of 500 tons in 1914 being:

|                |       |                |     |
|----------------|-------|----------------|-----|
| Sulphide.....  | 1,265 | Nitrite.....   | 922 |
| Prussiate..... | 1,147 | Phosphate..... | 682 |
| Ash.....       | 1,114 | Silicate.....  | 523 |

\* Mineral Resources U. S., 1915, p. 265.

† Mineral Industry, 1914, p. 675.

In this country about one fifth of the salt is mined or obtained from deep shaft mines\* or open cuts as rock salt, the rest is obtained by evaporation of the artificial or natural brines, bitterns, and sea water, using as heat the sun's rays or an artificial source.

Probably one half the *halite* is used for culinary and preservative purposes, over 1,000,000 tons per year are converted into sodium and chlorine compounds, chief among which are† sodium carbonate and bicarbonate, caustic soda and bleaching powder.

About 2,000 tons of metallic sodium are made in the United States yearly by the Castner process and until recently 8,000 to 9,000 tons of sodium cyanide for metallurgical purposes.

Minor uses are in glazing pottery and in many metallurgical processes and the manufactured carbonate and caustic soda have their large uses in glass and soap making, bleaching, etc.

*Soda nitre* is used in the manufacture of nitre for gunpowder, in the production of nitric acid, but chiefly for fertilizing purposes.

#### FORMATION AND OCCURRENCE OF SODIUM SALTS.

The economically important sodium compounds which occur as minerals are all deposits from weathering solutions assisted in the case of soda nitre probably by organic deposits.

*Halite* occurs in beds varying from a few feet to over three thousand feet in thickness, in all geologic ages‡ except the Archaean, commonly underlain by gypsum and anhydrite, sometimes alternating with clay, gypsum, anhydrite, marl and dolomite. It occurs also in nearly all water, from infinitesimal quantities to strong brines, and as incrustations on high planes in dry regions.

The solids in seawater average 3.5 per cent. The evaporation of 300 feet would only mean a bed of less than six feet thick. As it is difficult to imagine a steady subsidence sufficient to

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\* Salt mines are worked in Livingston County, New York; near Detroit, Michigan; in Ellsworth and Rice Counties, Kansas, and on Weeks and Avery Islands, Louisiana.

† Sodium sulphate (salt-cake) is first made and from this caustic soda, carbonate, bicarbonate, etc.

‡ Weinschenk gives Silurian "Pendschab," Carboniferous, England and North America; Dyas, north and middle Germany; Triassic, Württemberg and the Alps; Jurassic, Bex, Switzerland; Cretaceous, Algiers; Tertiary, Carpathians, Spain, Sicily; Armenia, Persia. "Grundzüge des Gesteinskunde," 243.

explain deposits 1,000 to 3,000 ft. thick the Bar theory of Ochsenius\* is generally accepted. For the dissolved constituents to separate there is needed a concentration of the solution, usually a land-locked basin with a shallow bar between it and the sea, the surface layers sinking as they become denser.

Michigan, New York, Ohio and Pennsylvania produce salt derived from "the evaporation of some great sea." At least six successive periods of evaporation took place and each bed of salt is underlain by one or more of dolomite, anhydrite, and marl.

Enormous dome-shaped deposits of very pure rock salt surrounded on all sides by clay occur in Louisiana. On Weeks Island it is at least 4,000 ft. thick and very pure. At Petite Anse there are 2,263 feet of pure salt, then 70 feet of foreign matter, then more salt to an unknown depth. Curiously, they are *overlain* by enormous beds 200 to 600 feet thick of gypsum and anhydrite or oil-bearing limestone. The conditions of formation are not understood.†

In the drier western states halite is found as at Salton, California, in crusts 10–20 inches thick, then mud, then another salt crust and the whole over hard clay. Similar deposits occur in North Africa.

Famous foreign salt deposits are Wieliczka, Poland; Cheshire, England; Salzburg, Tyrol.

### The Sulphates of Soda.

Like halite, the sulphates of soda are derived from the weathering solutions but rather in inland "lakes" lacking much calcium or magnesium. Little is formed in marine basins, the sulphuric acid being there deposited as gypsum, anhydrite, kieserite, etc.

As with the sulphates of lime, p. 440, strong salt solutions dehydrate therefore the hydrous sulphate mirabilite is deposited from pure solution, while the anhydrous sulphate thenardite deposits in presence of much halite.

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\* "Die Bildung der Steinsalzlager," Halle, 1877.

The reason for the non-evaporation of the residual salts is that the dense solutions in time reach the level of the bar and the residual bitter escapes. The Gulf of Karaboghaz, east side of Caspian Sea, is instanced by Clarke.

"Data Geochemistry," p. 211. Bulletin Geol. Surv. 491.

† Lindgren, "Mineral Deposits," 288.

Near Laramie, Wyoming, are "lake deposits 20-30 feet deep, principally of sodium sulphate, mirabilite,  $\text{Na}_2\text{SO}_4 + 10\text{H}_2\text{O}$ ." The upper few inches is nearly pure white below the crystals and intermixed mud containing 36 per cent.  $\text{Na}_2\text{SO}_4$  (pure mirabilite containing 44 per cent.).

The same mineral separates from the Great Salt Lake, when the temperature is low, and is heaped up by the waves on the beaches where, if not collected, it redissolves as soon as the temperature rises, and a similar winter formation takes place at Lacu Sarat, Roumania.

#### Soda Nitre.

Soda nitre forms in small amounts as the result of the action of bacteria on organic matter and the union of the nitric acid with soda, and may accumulate in caves as at Holmdale, Idaho. Somewhat larger deposits of less certain origin occur in Death Valley, California, along the shore line of an ancient sea.\*

The world's great deposits are in Tarapaca and Antofagasta, Chili, a rainless, desolate region 3,000 feet above the sea between the Andes and the Coast Ranges and near the latter. Often the deposits are only ten miles from the sea.

The area is broken by transverse ranges into a series of plateaus or "pampas" which slope from the Andes to the coast ranges. Superficial beds of common salt and soda nitre 1 to 6 ft. thick occur under a few feet of earth, the nitrate often on somewhat higher ground, but at other times they are mixed indiscriminately, the soda nitre averaging about 25 per cent.

The impure soda nitre or "caliche" is hand-picked from the associated chlorides and sulphates and refined.

The origin is not certain.† The soil of Venezuela and other parts of South America is unusually rich in nitrates. Mountain floods, which occur at intervals of seven or eight years, may have carried the soluble nitrate to the pampas where it is again deposited. Other theories are the leaching of bird guano and the mingling with the salt waters of an enclosed basin.

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\* *Mineral Industry*, 1914, p. 673.

† Discussion, Clarke, Bulletin U. S. Geol. Survey, 491, pp. 242-246.

**The Carbonates of Sodium.**

The carbonates of sodium occur in soils and in certain lakes and "playa" lakes (dry in summer, flooded in the wet season). The white efflorescence on the "playas" is a mixture of these with chlorides. Trona is much more common than the laboratory product, natron.

The manner of their deposition from weathering solutions is variously attributed to:

1. Direct deposition of the leachings of rocks\* poor in lime and rich in soda as in the Lahontan Lakes of Nevada, in which the decomposing rocks are rhyolites and andesites, or Owen's Lake, California, where the waters run through volcanic ash.
2. Reduction from alkaline sulphates by algæ† as in part at least explaining the natron lakes of Egypt.
3. Double decomposition between sodium sulphate or chloride and calcium bicarbonate as explaining some Hungarian deposits.

Examples of deposits, some of which have been worked are:

*Searles Lake, California.*‡—Contains trona in "fish bone" crystals which look like flat splinters of wood projecting into the ground like roots for 6–7 inches.

*Green River, Wyoming,* where borings in sandstone yielded at 700 feet an almost concentrated solution of carbonates.

*Ragtown, Nevada,* where analyses showed an average  $\text{Na}_2\text{CO}_3$  47,  $\text{NaHCO}_3$  31,  $\text{H}_2\text{O}$  16 per cent.

*Owen's Lake, California.*—The dissolved salts being one third carbonates of soda.

**HALITE.—Rock Salt, Common Salt.**

COMPOSITION.— $\text{NaCl}$ , (Na 60.6 per cent.), usually impure.

GENERAL DESCRIPTION.—Halite occurs frequently granular, sometimes coarse, often dense and mixed with clay. Colors white, gray, brown or blue and red from uncertain coloring material, green from copper, brown from bituminous substances. In dry countries it occurs as a fibrous efflorescence. It is liable to absorb moisture and becomes damp, especially when containing calcium or magnesium chlorides. It is known by its taste.

\* Bulletin, U. S. Geol. Survey, 149, 229.

† *Ibid.*, 230.

‡ *Mineral Industry*, 1914, p. 676.

**CRYSTALLIZATION.**—Isometric in cubes and cavernous crystals and cubic cleavages often with symmetrical etchings, more rarely other forms.

FIG. 414.

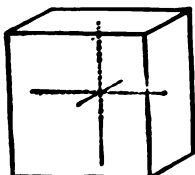


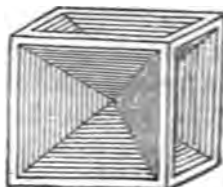
FIG. 415.



FIG. 416.



FIG. 417.



**Physical Characters.** H., 2.5. Sp. gr., 2.4 to 2.6.

LUSTRE, vitreous.

TRANSLUCENT to transparent.

STREAK, white.

TENACITY, brittle.

COLOR, white, colorless, yellow, brown, deep blue.

TASTE, salt.

CLEAVAGE, cubic.

**BEFORE BLOWPIPE, ETC.**—Decrepitates violently, fuses very easily and colors the flame yellow and may be volatilized. Easily soluble in cold water.

**SIMILAR SPECIES.**—The taste distinguishes it from all other minerals.

**REMARKS.**—The mode of occurrence, type localities and uses have been described on pp. 422-423.

#### MIRABILITE. — Glauber Salt.

**COMPOSITION.** —  $\text{Na}_2\text{SO}_4 + 10\text{H}_2\text{O}$  ( $\text{Na}_2\text{O}$  19.3,  $\text{SO}_3$  24.8,  $\text{H}_2\text{O}$  55.9 per cent.).

**GENERAL DESCRIPTION.** — Translucent, white, fibrous crusts or monoclinic crystals, closely resembling those of pyroxene in form and angle. On exposure loses water and falls to powder.

**Physical Characters.** H., 1.5 to 2. Sp. gr., 1.48.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TASTE, salty and bitter.

COLOR, white or faintly greenish.

**BEFORE BLOWPIPE, ETC.** — On charcoal fuses, colors the flame yellow and leaves a mass which will stain bright silver. In closed tube yields much water. Easily soluble in water.

**REMARKS.**—Type occurrences have been described on p. 423. Others are the bottom of the Bay of Kara Bougas, an inlet of the Caspian Sea, in deposits sometimes a foot in thickness. Massive at Logróno, Spain; without salt in great layers at Bompensieri, Sicily; Tiflis, Tarapaca, Chile; New Albany, Ind. In gypsum in Westmoreland and as a sublimation product at Vesuvius.

**THE NARDITE.**— $\text{Na}_2\text{SO}_4$ . Twinned tabular orthorhombic crystals and as an efflorescence. Soluble in water. Found at Borax Lake, Cal., and Villa Rubia, Spain, in good crystals, dense material at Stassfurt, Prussia, Rio Verde, Arizona, etc.

**GLAUBERITE.**— $\text{Na}_2\text{SO}_4 \cdot \text{CaSO}_4$ . Tabular monoclinic crystals and lamellar masses in rock salt and in the mud of borax lakes.

### SODA NITRE.—Chili Saltpetre.

**COMPOSITION.**— $\text{NaNO}_3$ , ( $\text{Na}_2\text{O}$  36.5,  $\text{N}_2\text{O}_5$  63.5 per cent.).

**GENERAL DESCRIPTION.**—Rather sectile granular masses or crusts of white color, occurring in enormous beds and as an efflorescence. Rarely found as rhombohedral crystals of the forms of calcite. On exposure crumbles to powder.

**Physical Characters.** H., 1.5 to 2. Sp. gr., 2.24 to 2.29.

LUSTRE, vitreous.

TRANSPARENT.

STREAK, white.

TENACITY, brittle.

COLOR, colorless, white or yellowish. TASTE, cooling and salty.

**BEFORE BLOWPIPE, ETC.**—On charcoal deflagrates less violently than nitre and becomes liquid. Colors the flame yellow. Very easily soluble in water.

**REMARKS.**—The occurrence and uses have been described on pp. 422, 424.

### TRONA.—Urao.

**COMPOSITION.**— $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 + 2\text{H}_2\text{O}$ , ( $\text{Na}_2\text{O}$  41.2,  $\text{CO}_2$  38.9,  $\text{H}_2\text{O}$  19.9.).

**GENERAL DESCRIPTION.**—Beds and thin crusts of white glistening material, often fibrous and occasionally in monoclinic crystals. It is not altered in dry air.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, vitreous, glistening. Color, white, gray, yellowish. Streak, white. H, 2.5 to 3. Sp. gr., 2.11 to 2.14. Taste, alkaline.

**BEFORE BLOWPIPE, ETC.**—Fuses easily, coloring flame yellow. In closed tube yields water and carbon dioxide. Easily soluble in water. Effervesces vigorously in cold dilute acids.

**REMARKS.**—The chief occurrences have been described on p. 425; others are Armenia, Venezuela and British East Africa.

**GAY-LUSSITE.**— $\text{Na}_2\text{CO}_3 \cdot \text{CaCO}_3 \cdot 5\text{H}_2\text{O}$ . White monoclinic pyramidal crystals at Soda Lake, Nevada; Venezuela, etc.

## THE LITHIUM MINERALS.

The minerals described are :



|                  |                    |  |            |
|------------------|--------------------|--|------------|
| <i>Phosphate</i> | <i>Amblygonite</i> | $\text{Li}(\text{Al.F})\text{PO}_4$    | Triclinic  |
| <i>Silicates</i> | <b>Spodumene</b>   | $\text{LiAl}(\text{SiO}_3)_2$          | Monoclinic |
|                  | Lepidolite         | $\text{R}_2\text{Al}(\text{SiO}_3)_3$  | Monoclinic |
|                  | Petalite           | $\text{LiAl}(\text{Si}_2\text{O}_6)_2$ | Monoclinic |

Lithia is also a constituent of a series of double phosphates such as triphyllite and triplite, of less well-known silicates cookeite, eucryptite and of certain varieties of tourmaline.

#### ECONOMIC IMPORTANCE.

About 3,000 tons of the phosphate amblygonite were produced\* in the Black Hills deposits near Keystone and shipped to Newark for treatment. The silicates are little if at all used.

The chief use now is as lithia hydrate in prolonging the life of a storage battery. There are small uses in photography, medicine and fireworks. The carbonate was formerly extensively used as a remedy for rheumatism.

#### FORMATION AND OCCURRENCE OF LITHIUM MINERALS.

Lithia is present in most igneous rocks but chiefly in pegmatites of soda-rich rocks.

Examples are:

*Keystone, South Dakota.*—Spodumene and amblygonite, the former in enormous crystals, the latter in nodules up to 1,000 lbs. in weight.

*Montebras, France:* Amblygonite. *Pala, California:* Amblygonite, lepidolite. *Branchville, Conn:* Amblygonite, triphyllite, spodumene. *Chesterfield, Mass.:* Spodumene. *Paris and Hebron, Maine:* Amblygonite, lepidolite.

#### AMBLYGONITE.

COMPOSITION. —  $\text{Li}(\text{Al.F})\text{PO}_4$ , ( $\text{Li}_2\text{O}$  10.1 per cent. generally partly replaced).

GENERAL DESCRIPTION. — A cleavable compact massive or columnar mineral somewhat resembling orthoclase. Sometimes in large indistinct crystals.

PHYSICAL CHARACTERS. —  $H = 6$ ,  $\text{Sp. Gr.} = 3.01\text{--}3.09$ . Lustre, pearly to vitreous. Streak, white. Brittle. Translucent. Color, usually white, sometimes with green, blue, yellow or brown tints.

BEFORE THE BLOWPIPE, ETC. — Gives characteristic red lithia flame, fuses with intumescence to an opaque white globule. Soluble in sulphuric acid when powdered.

REMARKS. — Occurs in quantity at Pala, California.

USES. — Is an important source of lithium and carries a comparatively high percentage of this element.

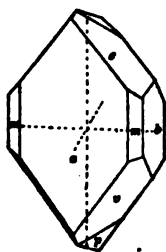
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\* *Mineral Industry*, 1914, p. 500.

## SPODUMENE.

COMPOSITION.— $\text{LiAl}(\text{SiO}_3)_2$ ,  $\text{Li}_2\text{O}$  8.4 per cent. with some sodium replacing lithium.

FIG. 418.



GENERAL DESCRIPTION.—White or greenish-white monoclinic crystals, sometimes of enormous size, more rarely small emerald-green, and larger lilac colored crystals. Also in masses. Characterized by an easy parting parallel  $a$  in addition to the prismatic cleavage.

CRYSTALLIZATION.—Monoclinic. Axes  $a : b : c = 1.124 : 1 : 0.636$ ;  $\beta = 69^\circ 40'$  Common. forms: the pinacoids  $a$  and  $b$ , the unit prism,  $m$ , unit pyramid  $p$ , the pyramid  $v = (a : b : 2c)$ ;  $\{221\}$  and the clinodome  $e = (\infty a : b : 2c)$ ;  $\{021\}$ . Supplement angles:  $mm = 93^\circ$ ;  $pp = 63^\circ 31'$ ;  $vv = 88^\circ 34'$ ;  $ee = 107^\circ 24'$ . Optically +. Axial plane  $b$ .

Physical Characters. H., 6.5 to 7. Sp. gr., 3.13 to 3.20.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white, pale-green, emerald, green, pink, purple.

BEFORE BLOWPIPE, ETC.—Becomes opaque, intumesces, swells and fuses to a white or colorless glass, coloring the flame purple-red, especially with hydrochloric acid. Insoluble in acids.

SIMILAR SPECIES.—Distinguished by its tendency to split into thin pearly plates and by the red flame.

ALTERATIONS.—Spodumene alters to  $\beta$  *spodumene* by replacement of half of  $\text{Li}_2\text{O}$  by  $\text{Na}_2\text{O}$  and by further alteration forms *cymatolite*, a mixture of albite and muscovite.

REMARKS.—Prominent localities are mentioned, p. 428. The gem varieties described later occur at Alexander Co., N. C. (*hiddenite*), Pala, Calif. (*kunzite*), Minas Geraes, Brazil, and Madagascar (*spodumene*).

## LEPIDOLITE. — Lithia Mica.

COMPOSITION.— $\text{R}_3\text{Al}(\text{SiO}_3)_2$ . R = Li, K, NaF, etc.  $\text{Li}_2\text{O}$ , 4 to 6 per cent.

GENERAL DESCRIPTION.—Scaly, granular masses of pale-pink color and gray transparent crystals, with easy cleavage into elastic plates.

PHYSICAL CHARACTERS.—Translucent. Lustre, pearly. Color, rose, violet, lilac, gray, white. Streak, white. H., 2.5 to 4. Sp. gr., 2.8 to 2.9. Sectile. Cleavage, basal.

**BEFORE BLOWPIPE, ETC.**—Fuses easily to a white glass. Colors the flame purple-red. Partially soluble in hydrochloric acid.

**REMARKS.**—Found in considerable quantity near Pala, San Diego Co., California, with red tourmaline, also at Paris and Hebron, Me., Chesterfield, Mass., Rozena, Moravia, Utö, Sweden, and elsewhere.

**USES.**—It is a source of lithium salts.

#### PETALITE.

**COMPOSITION.**— $\text{LiAl}(\text{Si}_2\text{O}_5)_2$ .

**GENERAL DESCRIPTION.**—Glassy white or gray foliated and cleavable masses and rarely minute, colorless crystals, like pyroxene in form.

**PHYSICAL CHARACTERS.**—Transparent to translucent. Lustre, vitreous. Color, colorless, white, gray, occasionally pink. Streak, white. H., 6 to 6.5. Sp. gr., 2.39 to 2.46.

**BEFORE BLOWPIPE, ETC.**—Phosphoresces with gentle heat; with strong heat, whitens and fuses on the edges and colors the flame carmine. Insoluble in acids.

**REMARKS.**—Found at Elba in tourmaline granite and in the iron mines of Utö, Sweden. In this country at Bolton, Mass., and Peru, Maine.

### THE AMMONIUM MINERALS.

The minerals described are :

|                 |                     |                              |              |
|-----------------|---------------------|------------------------------|--------------|
| <i>Chloride</i> | <i>Sal Ammoniac</i> | $\text{NH}_4\text{Cl}$       | Isometric    |
| <i>Sulphate</i> | <i>Mascagnite</i>   | $(\text{NH}_4)_2\text{SO}_4$ | Orthorhombic |

The hypothetical compound radical ammonium, has never been separated from its compounds. Its occurrence in nature is rare, and its minerals while of great theoretical interest do not occur in commercial quantities. Its compounds, many of which are of great importance in the arts, are obtained by the dry distillation of organic matter, and notably of bituminous coal in the process of gas manufacture, from coke ovens, from the dry distillation of bones and from the gases of blast furnaces using coal as fuel.

#### SAL AMMONIAC.

**COMPOSITION.**— $\text{NH}_4\text{Cl}$ , ( $\text{NH}_4$  33.7, Cl 66.3 per cent.).

**PHYSICAL CHARACTERS.**—Transparent to translucent. Lustre, vitreous. Color, colorless, white, yellowish. Streak, white. H., 1.5 to 2. Sp. gr., 1.53. Taste, pungent, salt. Cleavage, parallel to octahedron.

**BEFORE BLOWPIPE, ETC.**—Sublimes, without fusion, as white fumes. With soda or quicklime, gives odor of ammonia. Easily soluble in water.

**REMARKS.**—Occurs near volcanoes, burning coal-beds and in guano deposits. Artificially, it is a by-product from gas-works.

#### MASCAGNITE.

**COMPOSITION.**— $(\text{NH}_4)_2\text{SO}_4$ , ( $(\text{NH}_4)_2\text{O}$  39.4,  $\text{SO}_4$  60.6 per cent.).

**GENERAL DESCRIPTION.**—Yellowish, mealy incrustations on lava or in guano. Rarely in orthorhombic crystals.

**PHYSICAL CHARACTERS.**—Translucent. Lustre, dull or vitreous. Color, lemon-yellow, yellowish or gray. Streak, white. H., 2 to 2.5. Sp. gr., 1.76 to 1.77. Taste, pungent and bitter.

**BEFORE BLOWPIPE, ETC.**—Sublimes without fusion. With soda or quicklime, yields odor of ammonia. Easily soluble in water.

**REMARKS.**—Occurs on lava or guano or near burning coal-beds. It is artificially made from the ammoniacal liquors of gas-works, coke-ovens, and blast furnaces and to a less extent is a by product from the manufacture of boric acid in Tuscany.

### THE BARIUM MINERALS.

The minerals described are:

|                   |                      |                                     |              |
|-------------------|----------------------|-------------------------------------|--------------|
| <i>Sulphate</i>   | <b>Barite</b>        | BaSO <sub>4</sub>                   | Orthorhombic |
| <i>Carbonates</i> | <b>Witherite</b>     | BaCO <sub>3</sub>                   | Orthorhombic |
|                   | <i>Barytocalcite</i> | BaCa(CO <sub>3</sub> ) <sub>2</sub> | Monoclinic   |

Barium occurs in a few silicates,\* hyalophane, harmotome, also in the phosphate uranocircite, the nitrate, nitrobarite and the carbonates alstonite and barytocelestite.

### ECONOMIC IMPORTANCE.

The production of barite in this country in 1915 was 108,547 short tons, valued at \$381,032, chiefly from Missouri, Georgia and Tennessee. England and Germany usually are very large producers.

In 1914 there was imported† into this country about 50,000 tons of barium salts, chiefly baryta, BaO, but also *blanc fixé*, lithophone, and the carbonate, binoxide and chloride.

Barite and witherite are employed chiefly in the manufacture of barium sulphide, chloride and oxide.

Barium sulphide by heating barite with coal slack or pitch, barium chloride by dissolving witherite in hydrochloric acid and barium oxide by roasting witherite. From these the other salts are made.

The more important uses are‡ as pigments in the ground state or as the artificial compounds *blanc fixé* and lithophone; and as the peroxide used in making hydrogen peroxide. Minor uses are in the making of white rubber, artificial ivory, boiler compounds, and special glasses and in preventing efflorescence on bricks. There is a reported§ use by Germany in the manufacture

\* Also celsian, barylite, brewsterite, edingtonite, barytbiotite.

† *Mineral Industry*, 1914, p. 65.

‡ *Mineral Resources U. S.*, 1914, p. 63.

§ *Mineral Industry*, 1914, p. 71.

of sulphuric acid by oxidizing the  $H_2S$  released on treatment of the sulphide by hydrochloric acid.

#### FORMATION AND OCCURRENCE OF BARIUM DEPOSITS.

Barium is present in the earth's crust to the extent of about one tenth of one per cent., probably as silicate and the leucite and analcite rocks of Montana and Wyoming contain as much as one per cent.

The economic deposits are sulphate or carbonate and occur as:  
**Veins Associated with Metallic Ores.**

Barite is one of the most common gangue minerals. It is separated\* by hand picking in large quantities from the lead and zinc veins of Durham, Northumberland, Cumberland and Westmoreland, England; and vein barite is mined at Larn, Ireland. The only\* economic deposit of witherite is at Fourstones, Northumberland. Norway also produces barite as a by product in lead mining and in this country it is abundant in veins and cavities with galena and sphalerite in Jefferson and Franklin Counties, Missouri.

#### **Veins Free from Metallic Ores or as Replacements.**

Many such deposits occur in Virginia in limestone as a series of lenses and fractures sometimes connected. It is mined in open cuts in Washington Co., Mo. Occurs in veins in sandstones of Hesse.

#### **Residual Deposits.**

Imbedded in clay as a result of the weathering of a limestone or other rock. Such deposits occur in Missouri, Virginia, and Cartersville, Georgia. The compact Bologna spar occurs in marl near Bologna.

#### **BARITE.—Heavy Spar.**

COMPOSITION.— $BaSO_4$ , ( $BaO$  65.7,  $SO_3$  34.3 per cent.), sometimes with some strontia, silica, clay, etc.

GENERAL DESCRIPTION.—A heavy white or light-colored mineral, vitreous in lustre. It occurs in orthorhombic crystals, which are frequently united by their broader sides in crested divergent groups, and varying insensibly from this to masses made up of curved or straight lamellæ and cleavable into rhombic plates. It occurs also granular, fibrous, earthy, stalactitic and nodular.

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\* *Mineral Industry*, 1914, p. 71.

FIG. 419.

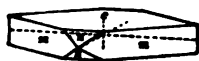


FIG. 420.

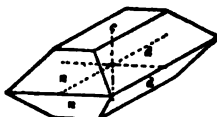


FIG. 421.



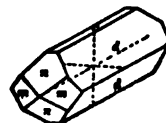
FIG. 422.



FIG. 423.



FIG. 424.



CRYSTALLIZATION.—Orthorhombic. Axes  $a : b : c = 0.815 : 1 : 1.314$ .

Unit prism  $m$ , base  $c$  and domes  $d = (\infty a : b : c)$ ;  $\{011\}$  and  $n = (a : \infty b : \frac{1}{2}c)$ ;  $\{102\}$  are the most common forms. Supplement angles are  $mm = 78^\circ 23'$ ;  $cd = 52^\circ 43'$ ;  $cn = 38^\circ 52'$ .

Optically +. The axial plane parallel  $b$  and the acute bisectrix normal to  $a$ . Axial angle with yellow light  $2E = 63^\circ 12'$ .

Physical Characters. H., 2.5 to 3.5. Sp. gr., 4.3 to 4.6.

LUSTRE, vitreous and pearly. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white or light shades of yellow, brown, red or blue.

CLEAVAGE, basal and prismatic ( $101^\circ 37'$  being prism angle).

BEFORE BLOWPIPE, ETC.—In forceps, decrepitates and fuses, coloring the flame yellowish-green and leaving an alkaline residue. With soda, on charcoal, gives sulphur reaction. Insoluble in acids.

SIMILAR SPECIES.—Distinguished among non-metallic minerals by its high specific gravity, insolubility and green flame.

REMARKS.—Type occurrences and uses are described on p. 432. Celebrated crystal localities are Derbyshire, England; Felsobanya, Hungary; Clausthal, Harz; Příbram, Bohemia; Bad Lands, Dakota; Sterling, Colorado; Cheshire, Connecticut.

## WITHERITE.

COMPOSITION.— $\text{BaCO}_3$  (BaO 77.7,  $\text{CO}_2$  22.3 per cent.).

GENERAL DESCRIPTION.—Heavy white or gray translucent masses of vitreous lustre, sometimes with small indistinct crystals or globular or botryoidal groups. Also granular, columnar and in crystals resembling those of quartz.

**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c \equiv 0.603 : 1 :$

FIG. 425.



0.730. Crystals always repeated twins resembling hexagonal pyramids with usually horizontal striations or deep grooves on the faces, Fig. 428. Optically —.

**Physical Characters.** H., 3 to 4. Sp. gr. 4.29 to 4.35.

LUSTRE, vitreous.

TRANSLUCENT.

STREAK, white.

TENACITY, brittle.

COLOR, white, gray, yellowish.

Cumberland, Eng.

**BEFORE BLOWPIPE, ETC.**—Fuses rather easily, coloring flame yellowish-green and becoming alkaline. Soluble in dilute hydrochloric acid, with effervescence, and less rapidly soluble in strong acid.

**SIMILAR SPECIES.**—Distinguished by its weight, effervescence with acids and green flame.

**REMARKS.**—Occurs in veins with lead ores at Fallowfield, Northumberland, and Alston, Cumberland, and in small amounts near Lexington, Ky., and on the north shore of Lake Superior. The most productive mines are at Fallowfield in England.

**BARYTOCALCITE.**— $\text{BaCa}(\text{CO}_3)_2$ . Monoclinic needles and masses of yellowish-white color found in the witherite locality. Always yields a weak manganese test.

### THE STRONTIUM MINERALS.

The minerals described are :

|           |              |                 |              |
|-----------|--------------|-----------------|--------------|
| Carbonate | Strontianite | $\text{SrCO}_3$ | Orthorhombic |
| Sulphate  | Celestite    | $\text{SrSO}_4$ | Orthorhombic |

Strontium constitutes about nine per cent. of the silicate brewsterite and is found in small amounts in aragonite, calcite, dolomite and barite.

### ECONOMIC IMPORTANCE.

In this country it is unimportant; none was produced\* in 1914 and the imported material was valued at \$1,016. Germany prior to the war used 100,000 tons of hydroxide per year in the beet sugar industry, there is a small use of iodide, bromide and lactate in medicine and the nitrate is the basis of the red fire used in fireworks and in night signals by boats or trains.

\* Mineral Resources U. S., 1914, p. 15.

Strontium hydroxide is made by converting the sulphate into sulphide, bringing this sulphide into solution in water, and precipitating the strontium hydroxide by means of sodium hydroxide. It is used to precipitate sugar from molasses as a strontium compound from which crystalline sugar can later be obtained.

#### FORMATION AND OCCURRENCE OF STRONTIUM MINERALS.

Strontium is estimated to constitute four one-hundredths of one per cent. of the earth's crust and the state in which it is combined is not known. The sulphate and carbonate occur:

##### In Veins.

The great Westphalian deposits of strontianite consist of large masses in veins in chalk and marl.

Occurrences in ore veins are Clausthal, Harz; Braunsdorf, Saxony; Strontian, Scotland; Condorcet, France.

##### In Chemical Sediments.

The Sicilian deposits of sulphur due to altered gypsum are rich in celestite and are an economic deposit. Concentrations in limestone are numerous as at Strontian Island, Lake Erie; Monroe Co., Michigan; Wallis, Switzerland. Concentrations with gypsum and halite occur at Ischl, Austria; Silver Lake, California and Gila Bend, Arizona; Bristol, England.

#### CELESTITE.

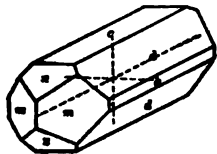
COMPOSITION— $\text{SrSO}_4$ , (SrO 56.4,  $\text{SO}_3$  43.6 per cent.).

GENERAL DESCRIPTION.—A white translucent mineral, often with a faint bluish tinge. Occurs in tabular to prismatic orthorhombic crystals, fibrous and cleavable masses, and rarely granular. It is notably heavy, and has a general resemblance to barite.

CRYSTALLIZATION. — Orthorhombic. Axes  $a : b : c = 0.779 : 1, : 1.280$ .

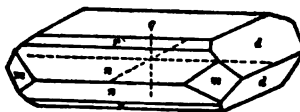
The common forms are the base  $c$ , the unit prism  $m$  and the domes  $n$  and  $d$ . The supplement angles are  $mm = 75^\circ 50'$ ;  $cn = 39^\circ 25'$ ;  $cd = 52^\circ$ .

FIG. 426.



Sicily.

FIG. 427.



Lake Erie.



Optically +. Axial plane  $b$ . Acute bisectrix normal to  $a$ . Axial angle with yellow light  $2E = 88^\circ 38'$ .

**Physical Characters.** H., 3 to 3.5. Sp. gr., 3.95 to 3.97.

LUSTRE, vitreous or pearly. TRANSPARENT, nearly opaque.

STREAK, white. TENACITY, brittle.

COLOR, white colorless, pale blue or reddish.

CLEAVAGE.—Basal and prismatic, yielding rhombic plates in which the rhomb angles are  $104^\circ 10'$  and  $75^\circ 50'$ .

BEFORE BLOWPIPE, ETC.—Fuses easily to a white pearly glass and colors the flame crimson. Usually decrepitates and becomes alkaline. With soda on charcoal gives sulphur reaction. Insoluble in acids.

SIMILAR SPECIES.—Distinguished from barite by its red flame and from other minerals by its high specific gravity, insolubility and red flame.

REMARKS.—Occurs as described on p. 435.

### STRONTIANITE.

COMPOSITION.— $\text{SrCO}_3$ , (SrO 70.1,  $\text{CO}_2$  29.9 per cent.).

GENERAL DESCRIPTION.—Usually found as yellowish-white or greenish-white masses made of radiating imperfect needle crystals and spear-shaped crystals, very like those of aragonite. Also fibrous or granular and only rarely in distinct orthorhombic crystals, sometimes of considerable size.

**Physical Characters.** H., 3 to 3.5 Sp. gr., 3.68 to 3.72.

LUSTRE, vitreous. TRANSLUCENT.

STREAK, white. TENACITY, brittle.

COLOR, pale yellowish or greenish-white, also green, gray and colorless.

BEFORE BLOWPIPE, ETC.—In forceps swells, sprouts, colors the flame crimson, fuses on the edges and becoming alkaline. Soluble in cold dilute acids with effervescence.

SIMILAR SPECIES.—Differs from calcite and aragonite in fusibility, higher specific gravity and purer red flame. The flame and effervescence distinguish it from all other minerals.

REMARKS.—Strontianite is found in the United States chiefly in the State of New York, especially at Schoharie, Muscalonge Lake, Chaumont Bay, Theresa and Clinton. Strontianite used in the German beet sugar industry is largely obtained from Westphalia.

### THE CALCIUM MINERALS.

The minerals described are :

|                   |                  |                                       |              |
|-------------------|------------------|---------------------------------------|--------------|
| <i>Fluoride</i>   | <b>Fluorite</b>  | $\text{CaF}_2$                        | Isometric    |
| <i>Sulphates</i>  | <b>Anhydrite</b> | $\text{CaSO}_4$                       | Orthorhombic |
|                   | <b>Gypsum</b>    | $\text{CaSO}_4 + 2\text{H}_2\text{O}$ | Monoclinic   |
| <i>Carbonates</i> | <b>Aragonite</b> | $\text{CaCO}_3$                       | Orthorhombic |
|                   | <b>Calcite</b>   | $\text{CaCO}_3$                       | Hexagonal    |
|                   | <b>Dolomite</b>  | $\text{CaCO}_3, \text{MgCO}_3$        | Hexagonal    |
|                   | <b>Ankerite</b>  | $(\text{Ca, Mg, Fe})\text{CO}_3$      | Hexagonal    |

Among the calcium silicates considered are anorthite, labradorite, oligoclase, pyroxene, wollastonite, amphibole, garnet, vesuvianite, datolite, epidote, prehnite, and the zeolites; other non silicates are apatite, scheelite, autunite.

### ECONOMIC IMPORTANCE.

Aside from apatite and scheelite the economically important minerals are the carbonates, sulphates and fluoride.

#### Calcite.

Massive CALCITE and DOLOMITE, that is limestone and marble, are quarried in enormous quantities, the production of limestone exceeding in value even that of granite.

In 1914 there was produced in this country:\*

|                             | Estimated Weight, Tons. | Value.       |
|-----------------------------|-------------------------|--------------|
| Marble.....                 | 400,000                 | \$ 8,121,412 |
| Limestone burned as lime... | 3,380,963               | 13,247,676   |
| Other limestone.....        | 65,000,000              | 38,745,429   |
|                             | 68,780,963              | \$60,114,517 |

In addition to the uses enumerated above, limestone is used for hydraulic cements and in 1914 about 15,000,000 tons of Portland and other cements were produced in the United States, valued at \$80,533,203.

The great producers were in order of production:

| <i>Marble</i> | <i>Limestone</i> | <i>Lime</i>  | <i>Cement</i> |
|---------------|------------------|--------------|---------------|
| Vermont       | Pennsylvania     | Pennsylvania | Pennsylvania  |
| Tennessee     | Ohio             | Ohio         | Indiana       |
| Georgia       | Indiana          | Virginia     | New York      |
| Alabama       | New York         | Wisconsin    | Illinois      |

\* From Mineral Resources U. S., 1914, pp. 363-373, 864-880 and *Mineral Industry*, 1914, p. 84.

The great uses are in order of importance.

*Marble*, interior building, monuments, exterior building.

*Limestone*, road metal, flux, concrete, road ballast, fertilizers.

*Lime*, building, fertilizers (slaked), paper mills, tanneries, chemical work, including the soda ash process, bleaching powder, calcium carbide and glass and calcium cyanamide.

Minor uses were: Lithographic limestone, of which there was a small production in Kentucky and Iowa. Paris white, and whiting (ground chalk) used for kalsomine, putty and whitewash.

### Gypsum.

The commonest of all sulphates. The world uses\* over five million tons annually of which about two fifths comes from the United States, two fifths from France and half of the rest from Canada.

A comparatively small amount of fine-grained material is used as "alabaster" in statues, vases, columns, etc., and a large amount of poor-grade gypsum is ground as a fertilizer and of "selenite" as a constituent of wood pulp.

The rest, probably three fourths of all, is burned to produce varieties of quick or slow setting plaster of Paris, the use of which mixed with fibre or with layers of paper has greatly increased in modern buildings.

### Fluorite.

There is an increasing production and use of fluorite chiefly for use as a flux in basic open hearth steel. The production in 1915 in the United States was† 136,941 tons, valued at \$764,475. Nearly all came from Illinois and Kentucky and 83 per cent. of it was sold for use in the smelters.

Other uses are in producing opalescent glass and enamels, hydrofluoric acid and artificial cryolite‡ for use in the aluminum industry.

### FORMATION AND OCCURRENCE OF THE CALCIUM MINERALS.

The earth's crust is estimated to contain 3.18 per cent. of calcium, the percentage in the igneous rocks being a little higher,

---

\* *Mineral Industry*, 1914, p. 388; 1913, U. S., 2,357,752; France, 2,150,900; Canada, 577,442.

† *Mineral Resources U. S.*, 1915, p. 33.

‡ By fusion with bauxite and soda ash.

the greater portion being present in the plagioclase feldspars, the monoclinic pyroxenes, and the amphiboles.

The calcium minerals here considered may be classed as follows:

**Separation from Magma or Volcanic Exhalations.**

FLUORITE is an accessory in granite, gneiss, quartz porphyry, or syenite and sometimes in volcanic lavas as result of the action of fluorine-bearing gases.

ANHYDRITE crystals occur in cavities of lava at Santorin.

GYPSUM may form by the action of volcanic gases or sulphurous waters on rocks containing calcium as in the Sicilian sulphur deposit.\*

**In Veins as Gangue.**

FLUORITE,† is next to quartz and the carbonates, the most common gangue mineral, as occurring at Cripple Creek, Colorado, with gold tellurides; Kongsberg, Norway, with silver; Rosiclare, Illinois and Salem and Marion, Kentucky, with galena and sphalerite; north of England with lead; Saxon Voigtland with copper; and also as the most constant gangue of tin veins.

CALCITE, which next to quartz is the great gangue mineral, is comparatively rare in the old gold veins but occurs in the "old" silver veins, as at Kongsberg, Norway and Cobalt, Ontario, and abundantly in the "young" gold-silver veins and the galena sphalerite and pyrite veins.

DOLOMITE is often with calcite, as at Schneeberg, Saxony, and Příbram, Bohemia.

**In Veins Without Metals.**

FLUORITE.—Some of the veins of Illinois and Kentucky are nearly metal-free. Similar veins exist in San Roque, Argentina; sometimes they widen into caverns lined with fluorite, as at Macomb, New York, in which one cavern yielded fifteen tons of fluorite.

CALCITE.—The famous Iceland spar quarries of Reydarfjorden are veins in basalt, the most desirable material occurring in a red-gray clay.‡

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\* Weinschenck, "Grundzüge der Gesteinkunde," p. 240.

† Commercial deposits, Illinois, Kentucky, Weardale, Durham, Castleton, Derbyshire.

‡ Merrill's "Metallic Minerals," p. 136.

### Replacement Deposits.

FLUORITE may replace limestone as at the Florence mine, Montana,\* or the country rock near a tin deposit.†

DOLOMITE.—“Dolomitization” in metasomatic lead silver zinc deposits is attributed‡ to “metasomatic action of solutions containing  $\text{CO}_2$  and the  $\text{MgCO}_3$  upon the limestone.”

The increase in percentage of magnesium in the marine marls of Sweden, and in coral may be called replacements.

### As Chemical Sediments.

FLUORITE.—The dense fluorite of Stolberg, Harz, and the Pyrenees are apparently chemical sediments.§

ANHYDRITE is practically always a chemical sediment formed as such or formed as gypsum and changed by the action of brine|| to anhydrite.

The general association is with halite and gypsum. Large deposits exist at Zechstein, Harz, at Cordova, Spain; Stassfurt, Germany (300 feet thick); Hillsborough, Nova Scotia, under the gypsum, Spur, Texas; Louisiana; Southern California.

Beds of anhydrite and halite at the surface are rare. Usually the halite is dissolved and the anhydrite is changed to gypsum.

GYPSUM occurs in immense deposits as a chemical sediment: (a) Without salt beds indicating incomplete evaporation or subsequent leaching out of the salt as in the “Keupergrips” of Würtemberg,\*\* or the “gypsite” surface deposits with clay in Kansas, Oklahoma and Texas, and the “white sands” of Otero, New Mexico.

Near Fillmore,†† Utah, deposits of sand-like gypsum are formed by the winds blowing from the dry beds of playa lakes the minute crystals deposited by evaporation. The material forms dunes estimated to contain 450,000 tons of gypsum.

(b) With salt beds sometimes as an original deposit, usually underlying the salt and formed before the solutions were saturated with

\* Lindgren, “Mineral Deposits,” p. 164.

† Beyschlag, Vogt and Krusch (Truscott), p. 415.

‡ *Ibid.*, p. 718.

§ Weinschenck believes them to be secondary concentrations. “Grundzüge der Gesteinkunde,” p. 237.

|| Van't Hoff established that gypsum in  $\text{NaCl}$  solutions changes to anhydrite at about  $25^\circ \text{C}$ . to  $30^\circ \text{C}$ . Crystals of gypsum sinking through brine would be converted into anhydrite. Lindgren, p. 269.

\*\* “Grundzüge des Gesteinskunde” (Weinschenck), p. 240.

†† Merrill's “Non-Metallic Minerals,” p. 341.

salt, or at temperatures below 25° C. More frequently secondary to anhydrite and overlying it.

Famous deposits exist at Hillsborough, New Brunswick; Wentworth, Nova Scotia; Michigan; Northern Ohio; Erie and Onondaga Counties, New York; Fort Dodge, Iowa; Louisiana; Montmartre, France; the middle and north of England; and the alabaster locality of Castellina, Tuscany.

#### ~~CALCIUM CARBONATE~~ ~~Calcium Carbonate.~~

Chemical sediments of calcium carbonate occur. Springs form "calc sinter," rivers deposit "travertine" as at the waterfalls of Tivoli, thick beds of cellular material form known as "calc tufa" as at Pyramid and Winnemucca Lakes, Nevada.\* Stalactites and stalagmites form in caves. Flos ferri and compact onyx marbles, all are chemical sediments and when bicarbonate solutions enter the ocean there may be direct precipitation, as in the delta of the Rhone† and along the coast of Florida.

Sinter and travertine and other chemical sediments may be due in part to the cooperation of organisms, and chalk beds, fresh water marls, coral and shell limestones are formed from their shells and frameworks.

DOLOMITE may be a true sediment as at Ulm, Bavaria, and the deposit from the mineral spring at St. Allyre, France. More frequently it is an alteration or replacement of calcium carbonate.

#### FLUORITE. — Fluor Spar.

COMPOSITION.— $\text{CaF}_2$ , (Ca 51.1, F 48.9 per cent.).

GENERAL DESCRIPTION.—Usually found in glassy transparent cubes or cleavable masses of some decided yellow, green, purple or violet color. Less frequently granular or fibrous. Massive varieties are often banded in zigzag strips of different colors.

CRYSTALLIZATION. — Isometric. Usually cubes with modifying forms, especially the tetrahexahedron  $e = (a : 2a : \infty a)$ , {210}; the dodecahedron  $d$  and the hexoctahedron  $t = (a : 2a : 4a)$ , {421}. The cube faces are often striated parallel to the edges or with vicinal faces, p. 78, giving the appearance of a very flat tetrahexahedron. Rarely found in octahedrons, sometimes formed by

\* Bulletin 491 U. S. Geol. Survey, 525.

† *Ibid.*

‡ *Ibid.*, 536.

the grouping of small cubes in parallel positions. Penetration twins common.

Index of refraction for yellow light 1.4339.

**Physical Characters.** H., 4. Sp. gr., 3.01 to 3.25.

LUSTRE, vitreous.

TRANSPARENT to nearly opaque.

STREAK, white.

TENACITY, brittle.

COLOR, wine-yellow, green, violet, blue, colorless, brown, black.

FIG. 428.

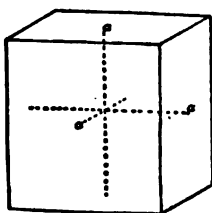


FIG. 429.

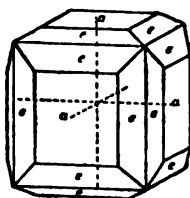
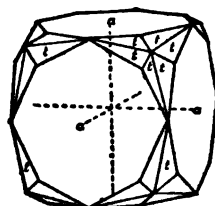


FIG. 430.



CLEAVAGE, octahedral at angles of  $70^{\circ} 31'$ .

BEFORE BLOWPIPE, ETC.—In closed tube at a low heat becomes phosphorescent. In forceps fuses to a white opaque glass and colors the flame red. Soluble in hydrochloric acid. Heated with acid potassium sulphate or sulphuric acid, fumes are set free which corrode glass.

SIMILAR SPECIES.—Recognized by cleavage and crystals and by the etching test. When cut it may resemble aqua marine, yellow topaz, etc., but is distinguished by softness.

REMARKS.—Occurrences and uses as stated on pp. 438 and 439. The brighter colored varieties are cut into vases, figures or imitation gems.

### ANHYDRITE.

COMPOSITION.— $\text{CaSO}_4$ , (CaO 41.2,  $\text{SO}_3$  58.8 per cent.).

GENERAL DESCRIPTION.—Granular, marble-like or sugar-like in texture, or as fibrous and lamellar masses of white, gray, bluish or reddish color. Cleavage in three directions at right angles. Rarely in orthorhombic crystals.

**Physical Characters.** H., 3 to 3.5. Sp. gr., 2.9 to 2.98.

LUSTRE, vitreous or pearly.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white, gray, bluish, brick-red. CLEAVAGES at right angles.

**BEFORE BLOWPIPE, ETC.**—Fuses to a white enamel and colors the flame red. With soda yields a sulphur reaction. Soluble slowly in acids.

**SIMILAR SPECIES.**—Differs from gypsum in being harder and not yielding decided test for water. Does not effervesce in acids like marble. Cleavage pseudo-cubic.

**Varieties.**

*Anhydrite of direct deposition*, usually dense, often enclosing a little clay or pyrite, halite, crystals of dolomite, boracite, fluorite, quartz. The color is white, red from iron, blue gray from clay, and an unexplained azure blue.

*Tripe stone (Gekröses stein)*.—Thin, closely folded layers in salt clay, such as occur in Galicia.

*Vulpinite*, a scaly siliceous? variety, which is cut and polished.

**REMARKS.**—Occurs as a chemical sediment, as described on p. 440, in mountain masses. It is rare in ore deposits. The best crystals are found embedded in the Stassfurt kieserite; others occur on massive anhydrite at Berchtesgaden, Bavaria.

**GYPSUM.—Selenite, Alabaster.**

**COMPOSITION.**— $\text{CaSO}_4 + 2 \text{H}_2\text{O}$ , (CaO 32.5,  $\text{H}_2\text{O}$  20.9,  $\text{SO}_3$  46.6 per cent.).

**GENERAL DESCRIPTION.**—Soft colorless white or slightly tinted masses, which may be granular or compact, or may be translucent and silky, fibrous or transparent and cleavable into plates and strips. Also in transparent cleavable monoclinic crystals.

FIG. 431.

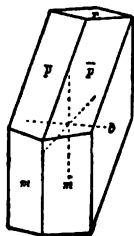


FIG. 432.

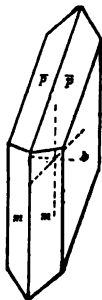


FIG. 433.



FIG. 434.



**CRYSTALLIZATION.** — Monoclinic.  $\beta = 80^\circ 42'$ . Axes  $a : b : c = 0.690 : 1 : 0.412$ .

Frequently the negative unit pyramid  $\bar{p}$ , with the unit prism  $m$



and clino-pinacoid  $b$ , Fig. 432, or these twinned, Fig. 433, or with dome  $r = (a : \infty b : \frac{1}{2}c)$ ,  $\{103\}$ ; Figs. 431 and 434. Supplement angles  $mm = 68^\circ 30'$ ;  $\overline{pp} = 36^\circ 12'$ ;  $cr = 11^\circ 29'$ .

**Physical Characters.** H., 1.5 to 2. Sp. gr., 2.31 to 2.33.

LUSTRE, pearly, silky, vitreous. TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle, laminæ flexible.

COLOR, white, colorless, gray, red, yellow, brown.

CLEAVAGE, clino-pinacoid perfect, unit ortho-dome fibrous, and ortho-pinacoid conchoidal. The cleavage fragments are rhombic plates with angles  $66^\circ$  and  $114^\circ$ .

BEFORE BLOWPIPE, ETC. — When heated quickly becomes white and opaque and fuses to an alkaline globule, coloring the flame yellowish-red. In closed tube yields water. Soluble in hydrochloric acid. The powdered dehydrated mineral when mixed with water will form a compact mass. Gives sulphur reaction.

#### VARIETIES.

*Selenite*.—Crystals or transparent cleavable masses.

*Satin Spar*.—Fine translucent fibrous varieties with sheen of silk.

*Alabaster*.—Compact and fine grained, suitable for carving.

*Rock Gypsum*.—Scaly, granular or dull colored and compact.

*Gypsite*.—An impure unconsolidated earthy or sandy form of gypsum, which in many places is found to contain a suitable percentage of foreign material so that the addition of a retarder is not necessary to effect a slow set.

SIMILAR SPECIES.—Talc, brucite, mica, calcite, heulandite, stilbite. It is softer than all but talc, lacks the greasy feeling of talc and is further characterized by quiet solubility, cleavages and calcium flame.

REMARKS.—The commonest of sulphates and chiefly a chemical sediment, as described on p. 440, and not usually an original separate but derived from anhydrite, usually in dense masses, which may include large crystals.

Famous crystal localities are Montmartre, Paris; Girgenti, Sicily; Wayne Co., Utah; Ellsworth Co., Ohio. In Mammoth Cave, Kentucky, it imitates rosettes, flowers, etc.

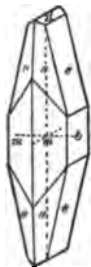
#### ARAGONITE.—Flos Ferri.

COMPOSITION.— $\text{CaCO}_3$ , (CaO 56.0,  $\text{CO}_2$  44.0 per cent.).

GENERAL DESCRIPTION.—Simple or pseudohexagonal crystals.

Also columnar and needle masses, oolitic, stalactitic and coral-like. The prevailing tint is white, but the color is occasionally violet or pale green.

FIG. 435.



Bilin, Bohemia.

FIG. 436.

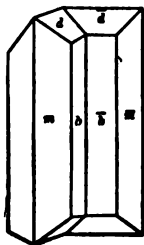
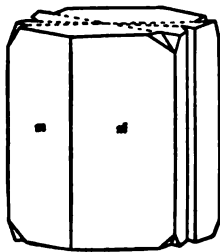
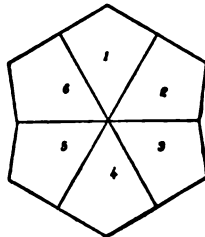


FIG. 437.



Herrengrund.

FIG. 438.



**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.622 : 1 : 0.721$ . Occasionally simple crystals, Fig. 435, with acute domes and pyramids such as  $e = (\infty a : b : 6c)$ ,  $\{061\}$ ; and  $s = (\frac{1}{3}a : b : 6c)$ ,  $\{9.12.2\}$ . These grade into needle-like forms. More frequently twinned, with twin plane  $m$ , giving prisms with pseudo-hexagonal cross sections, Figs. 437 and 438.

Supplement angles are:  $mm = 63^\circ 48'$ ;  $dd = 71^\circ 33'$ ;  $vv = 130^\circ 21'$ ;  $ee = 153^\circ 57'$ .

**Physical Characters.** H., 3.5 to 4. Sp. gr., 2.93 to 2.95.

LUSTRE, vitreous.

TRANSLUCENT or transparent.

STREAK, white.

TENACITY, brittle.

COLOR, white, violet, yellow, pale green.

CLEAVAGE.—Parallel to brachy pinacoid, prism, and brachy dome.

**BEFORE BLOWPIPE, ETC.**—Infusible, colors flame red. In closed tube decrepitates, loses weight and falls to pieces. With hydrochloric acid, dissolves with rapid effervescence. Powdered and boiled in a test-tube with dilute cobalt solution aragonite is turned to a lilac color.

**SIMILAR SPECIES.**—Natrolite and other zeolites which occur in needle crystals do not effervesce in acids. Strontianite and witherite have higher specific gravity and are fusible. Calcite has a lower specific gravity, differs in form, cleaves in three directions with equal ease yielding a rhombohedron of  $105^\circ 5'$ , and in powder is unaffected when boiled with cobalt solution.

**REMARKS.**—Occurs as crystals in gypsum and clay, as at Bastennes, France, and Molina, Aragon, and in the sulphur deposits of Sicily and the lead veins of Silesia. Coral like (*Mos ferri*) or fibrous at the Styrian and Carinthian iron mines and the Organ Mts., New Mexico. As needles in hollows of basalt. As the pearly layer of shells and the material of coral.

**CALCITE.**—Calcspars, Limestone, Marble, Iceland Spar, Etc.

**COMPOSITION.**— $\text{CaCO}_3$ , (CaO 56.0,  $\text{CO}_2$  44.0 per cent.).

**GENERAL DESCRIPTION.**—Yellowish white to white or colorless, more or less transparent crystals, of many shapes, all of which

FIG. 439.

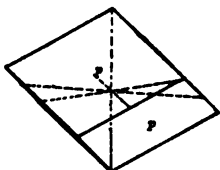
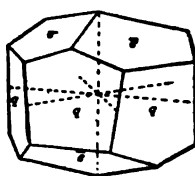


FIG. 440.



FIG. 441.



will cleave to a rhombohedron of  $105^\circ$ . Cleavable, coarse- and fine-grained, fibrous and loosely coherent masses. Crusts, stalactites.

**CRYSTALLIZATION.**—Hexagonal. Scalenohedral class, p. 48. Axis  $c = 0.854$ .

Occurs in many forms, of which the most common are the rhombohedra:  $p$ , the unit;  $\ell = (a : \infty a : a : \frac{1}{2}c)$ ,  $\{10\bar{1}2\}$ ;  $f = (a : \infty a : a : 2c)$ ,  $\{20\bar{2}1\}$ ;  $q = (a : \infty a : a : 16c)$ ,  $\{16.0.\bar{1}6.1\}$ ; scalenohedron:  $v = \frac{3}{8}a : 3a : a : 3c$ ,  $\{21\bar{3}1\}$  and unit prism. Twins are frequent. Supplement angles are  $pp = 74^\circ 55'$ ;  $\ell\ell = 45^\circ 3'$ ;  $ff = 101^\circ 9'$ ;  $qq = 119^\circ 24'$ . The polar edges  $vv$  are  $75^\circ 22'$  and  $35^\circ 36'$ .

**Optically** —. With very strong double refraction, but weak refraction ( $\alpha = 1.486$ ;  $\gamma = 1.658$  for yellow light).

**Physical Characters.** H., 3. Sp. gr., 2.71 to 2.72.

LUSTRE, vitreous to dull.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, yellow, white, colorless, or pale shades of red, green, blue, etc.

**CLEAVAGE**, parallel to the rhombohedron, therefore yielding diedral angles of  $105^\circ 5'$  and  $74^\circ 55'$ .

FIG. 442.

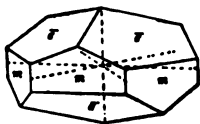


FIG. 443.



Dog Tooth Spar, Geikie.

FIG. 444.

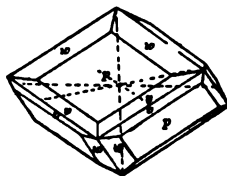


FIG. 445.

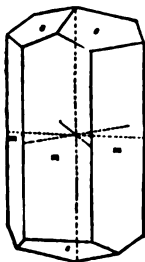


FIG. 446.

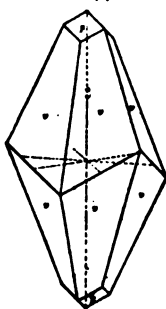


FIG. 447.

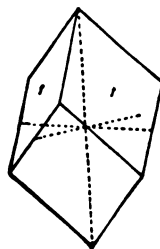


FIG. 448.



FIG. 449

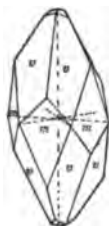


FIG. 450.

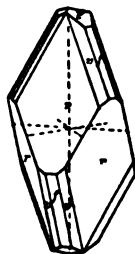
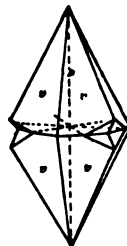


FIG. 451.



**BEFORE BLOWPIPE, ETC.**—Infusible. Becomes opaque and alkaline and colors flame red. Soluble readily in cold dilute acids, with vigorous effervescence.

**VARIETIES.**—The following are the most prominent varieties:

*Iceland Spar.*—Colorless, transparent crystals and masses.

*Dog Tooth Spar.*—Scalenohedral crystals, supposed to resemble canine teeth in shape.

*Fontainebleau Sandstone.*—Crystals containing up to 60 per cent. of sand.

*Satin Spar.*—Fibrous, with silky lustre.

*Argentine*.—Foliated, pearly masses.

*Marble*.—Coarse to fine granular masses, crystalline.

*Limestone*.—Dull, compact material, not composed of crystalline grains.

*Chalk*.—Soft, dull-white, earthy masses.

*Calcareous Marl*.—Soft, earthy and intermixed with clay.

*Stalactites*.—Icicle-like cylinders and cones, formed by partial evaporation of dripping water.

*Stalagmite*.—The material forming under the drip on the floor of the cavern.

*Travertine, Onyx*.—Deposits from springs or rivers, in banded layers.

Other names, such as *Hydraulic Limestone*, *Lithographic Limestone*, *Rock Meal*, *Plumbocalcite*, *Spartaite*, etc., are of minor importance, and are chiefly based on color, use, locality, etc., and do not generally indicate important structural or chemical differences.

**SIMILAR SPECIES.**—The distinctions from aragonite have been given under that mineral. Dolomite differs in slow partial solution in cold dilute acids, instead of rapid and complete effervescence.

**REMARKS.**—Occurrence and uses as described on pp. 439 to 441 and 437.

#### ANKERITE.

**COMPOSITION.**— $(\text{Ca}, \text{Mg}, \text{Fe})\text{CO}_3$ , sometimes containing manganese.

**GENERAL DESCRIPTION.**—Gray to brown rhombohedral crystals like those of siderite, also cleavable and granular masses and compact.

**PHYSICAL CHARACTERS.**—Translucent to opaque. Lustre, vitreous to pearly. Color, gray, yellow or brown. Streak, white or nearly so. H., 3.5 to 4. Sp. gr., 2.95 to 3.1. Brittle. Cleavage, rhombohedral.  $R \wedge R = 106^\circ 12'$ .

**BEFORE BLOWPIPE, ETC.**—Infusible, darkens and becomes magnetic. Soluble in acids with effervescence.

#### DOLOMITE.—Pearl Spar, Magnesian Limestone.

**COMPOSITION.**— $\text{CaCO}_3, \text{MgCO}_3$ , often contains iron or manganese.

**GENERAL DESCRIPTION.**—Small, white, pink or yellow, rhombohedral crystals, usually with curved faces, or more frequently white, massive marble, with coarse to fine grain; or gray, white and bluish, compact limestone.

**CRYSTALLIZATION.**—Hexagonal, class of third order rhombohedron, p. 54. Axis  $c' = 0.832$ . Usually the unit rhombohedron

FIG. 452.

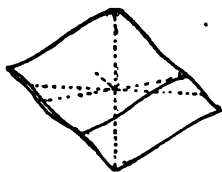
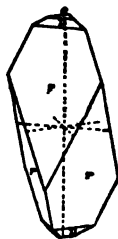


FIG. 453.



$\rho$ , Fig. 464, the faces curved or doubly curved (saddle-shaped). Often made up of smaller crystals. Sometimes the more acute rhombohedron  $r = (a : \infty a : a : 4c)$ ,  $\{4041\}$ . Supplement angles are  $\rho\rho = 73^\circ 45'$ ;  $rr = 113^\circ 53'$ .

Optically —, with even stronger double refraction than calcite.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 2.8 to 2.9.

LUSTRE, vitreous or pearly.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white, pink, greenish-gray, brown or black.

CLEAVAGE. Rhombohedral. Angles,  $106^\circ 15'$  and  $73^\circ 45'$ .

**BEFORE BLOWPIPE, ETC.**—Infusible, colors flame yellowish-red and becomes alkaline. With cobalt solution, becomes pink. *Fragments* are very slightly attacked by cold dilute acid. The powdered mineral is sometimes attacked vigorously by cold dilute acid, but sometimes is not. On heating there is a vigorous effervescence.

**SIMILAR SPECIES.**—Differs from calcite in effervescence, color with cobalt solution and frequent curvature of rhombohedral planes. It differs from siderite and ankerite in not becoming magnetic on heating.

**REMARKS.**—Dolomite is frequently the chief constituent of whole mountain ranges as in the Tyrol Alps and at Eifel. Formed possibly from calcite by infiltration of waters containing magnesium carbonate. Crystals are common in gypsum and on granular dolomite as at Hall, Tyrol, the zinc region of Missouri, and many places in the limestone region of Western New York.

The sugar grain structure is more common than with calcite owing to better development of the crystals.

## THE MAGNESIUM MINERALS.

The minerals described are:

|           |           |   |              |
|-----------|-----------|---|--------------|
| Hydroxide | Brucite   | $\text{Mg}(\text{OH})_2$                  | Hexagonal    |
| Sulphates | Kieserite | $\text{MgSO}_4 \cdot \text{H}_2\text{O}$  | Orthorhombic |
|           | Epsomite  | $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ | Orthorhombic |
| Carbonate | Magnesite | $\text{MgCO}_3$                           | Hexagonal    |

Most of the magnesium is combined with the great silicates such as amphibole, pyroxene, biotite, *enstatite*, *hypersthene*, *chrysolite*, *serpentine*, and *talc*, and the double salts *carnallite*, *kainite* and *dolomite*.

It forms also borates (*boracite*), chlorides, sulphates, and other silicates (*forsterite*, *sepiolite*, *chondrodite*, most of which are of very minor importance. The aluminate *spinel* is described.

#### ECONOMIC IMPORTANCE.

The world produces nearly 300,000 tons of crude and calcined magnesite annually of which two thirds comes from Austria-Hungary, one sixth from Greece and the rest chiefly from India and the United States.

The United States used in 1914 the equivalent of 132,000 short tons of calcined\* magnesite, of which about 127,000 tons was imported.

The minerals economically used are *magnesite*, *kieserite* and also *carnallite*, p. 418, and *dolomite*, p. 447.

#### Magnesite.

A use for the uncalcined material is said to be as a substitute for barite in paint. Some is made into chloride or sulphate, but nearly all is calcined, yielding according to temperatures used:

(a) *Caustic Magnesia* (moderate temperatures), with 3 to 8 per cent.  $\text{CO}_2$  left. In this state it will combine with magnesium chloride to a very strong "oxychloride" cement, much used for sanitary floors in buildings, steel cars, etc. Usually "fillers" of cork asbestos, etc., are added.

(b) *Dead-burned Magnesia* (*Incipient Fusion*†).—In this state will not slake or combine with chemicals and is used as basic bricks for lining Portland\* cement kilns, basic steel furnaces, kilns for sulphuric acid burning and electric furnaces.

\* One ton of calcined is equivalent to about  $2\frac{1}{2}$  tons of crude.

† The presence of 6–8 per cent. of iron in the Austrian material helps by lowering fusion point, thus giving a product which shrinks less.

(c) *Carbon dioxide* may be saved, but is said to interfere with proper calcining.

The calcined product is the source of magnesium bisulphite used in disintegrating wood for wood pulp paper.

#### **Kieserite.**

Epsomite or epsom salts are made by recrystallizing the Stassfurt kieserite (and also from bitterns and by-products in other processes). It is used as a laxative and in the textile industries (weighting and sizing cotton yarn) and as a fertilizer for clover hay.

The basic carbonate magnesita alba may be precipitated from epsomite or kieserite by sodium carbonate.

**Dolomite** is calcined in large amounts in Pennsylvania, dissolved and the "basic carbonate," magnesita alba, precipitated and used as a fireproof material and non conductor (for steam pipes) and many other purposes.

**Carnallite** is used in the liquid state in the oxychloride cement and for treating cotton goods.

It is also by electrolysis converted into metallic magnesium, now made in quantity in the shape of ribbon and as coarse grains, and used in flash lights, as a reducing agent in the preparation of some of the rarer elements, as a purifying agent to remove the last traces of oxygen from copper, nickel and steel and as a dehydrating agent for certain oils and for alcohol. The metal is steadily increasing in commercial importance.

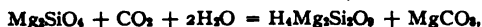
Carnallite with calcined magnesite is used as a fireproof paint.

#### **FORMATION AND OCCURRENCE OF MAGNESIUM MINERALS.**

The commercially important deposits of magnesite and kieserite are secondary, the *magnesite* being either due to alterations\* of basic eruptives or serpentine in veins or masses in the rock or to metasomatic replacement of limestone or dolomite occurring as beds; the *kieserite* to deposition from solutions as at Stassfurt.

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\* Solutions of  $\text{CO}_2$  may by attack on chrysolite produce both serpentine and magnesite,



or by attack on serpentine produce magnesite





**Magnesite in Veins or Masses in Basic Rocks or Serpentine.**

Usually as fine-grained porcelain-like material, the most important being veins in Eubœa, Greece, the largest 50 to 60 feet thick and 1,300 feet long. Other deposits worked are veins in serpentine at Grochberg, Silesia, and veins in Tulare, San Benito, and Santa Clara Counties, California. The magnesite may be in granular aggregates disseminated through the serpentinous rocks.

**Magnesite in Beds as Metasomatic Replacements.**

The world's great sources are the beds in Styria, Austria, resembling coarsely crystalline dolomite with some siderite. The largest bed at Veitsch is a huge lens 700 to 800 feet thick and about a dozen others are worked. A bed associated with limestones in the Swiss Tyrol is regarded as of similar origin, and the crystalline beds of Canada may be also of this type.

**Kieserite and Epsomite as Saline Residues.**

At Stassfurt, Prussia, kieserite constitutes about one fifth of a layer 190 feet thick, chiefly halite and carnallite, and is one of the constituents of the overlying mixed salts. In Albany County, Wyoming, are several lakes, in which deposits of epsomite are formed on a very large scale.

**BRUCITE.**

COMPOSITION.— $\text{Mg}(\text{OH})_2$ , (MgO 69.0,  $\text{H}_2\text{O}$  31.0 per cent.).

GENERAL DESCRIPTION.—White or gray translucent foliated masses with pearly or wax-like lustre. Also fibrous and in tabular hexagonal crystals.

Physical Characters. H., 2.5. Sp. gr., 2.38 to 2.4.

LUSTRE, pearly or wax-like. TRANSLUCENT.

STREAK, white. TENACITY, sectile and flexible.

COLOR, white, bluish, greenish. CLEAVAGE, basal.

BEFORE BLOWPIPE, ETC.—Infusible, becomes alkaline, and with cobalt solution becomes pink. Yields water in closed tube. Soluble in hydrochloric acid.

SIMILAR SPECIES.—Harder and more soluble than foliated talc or gypsum, and quite infusible.

REMARKS.—Brucite is usually found in serpentine or limestone with magnesite or hydromagnesite. On exposure it becomes coated with a white powder, and is some times changed to serpentine or hydromagnesite. Its most prominent American locality

is at Texas, Pa., also at Fritz Island in the same State; at Brewsters, N. Y., and Hoboken, N. J.

#### KIESERITE.

COMPOSITION.— $\text{MgSO}_4 + \text{H}_2\text{O}$ , MgO, 29.0,  $\text{SO}_2$  58.0,  $\text{H}_2\text{O}$  13 per cent.

GENERAL DESCRIPTION.—Coarse to fine granular or compact masses of white or yellowish color. Rarely in monoclinic pyramids. H., 3 to 3.5. Sp. gr., 2.52 to 2.57.

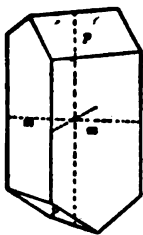
BEFORE BLOWPIPE, ETC.—Fuses easily, heated on coal with cobalt solution becomes pink. Slowly but completely soluble in water.

REMARKS.—As stated on p. 452, occurs in enormous quantities at Stassfurt, often mixed with carnallite and other salts. Also found at Hallstadt and Kalusez, Galicia.

#### EPSOMITE. — Epsom Salt.

COMPOSITION.— $\text{MgSO}_4 + 7\text{H}_2\text{O}$ , (MgO 16.3,  $\text{SO}_2$  32.5,  $\text{H}_2\text{O}$  51.2 per cent.).

FIG. 454.



GENERAL DESCRIPTION.—A delicate white fibrous efflorescence or earthy white crust with a characteristic bitter taste. Also common in solution in mineral water. Occasionally in crystals, Fig. 454, which are noticeable as representing class of the sphenoid in the orthorhombic system, p. 41. Optically —.

PHYSICAL CHARACTERS.—Transparent or translucent. Lustre, vitreous or dull. Color and streak, white. H., 2 to 2.5. Sp. gr., 1.75. Taste, bitter and salt.

BEFORE BLOWPIPE, ETC.—Fuses at first, but becomes infusible after the water of crystallization has been driven off. With cobalt solution becomes pink. In closed tube yields acid water. Easily soluble in water.

REMARKS.—Epsomite is formed by action of the sulphuric acid of decomposing sulphides, upon such magnesian minerals as serpentine and talc and in considerable quantities in caves in limestone as at Mammoth Cave, Kentucky. At Epsom, England, it is a fibrous efflorescence. At Stassfurt it occurs in granular masses due to alteration of kieserite.

#### MAGNESITE.

COMPOSITION.— $\text{MgCO}_3$ , (MgO 47.6,  $\text{CO}_2$  52.4 per cent.), with sometimes iron or manganese replacing part of the magnesium.

GENERAL DESCRIPTION.—White porcelain-like masses or dense rounded nodules or marble-like with coarse grain. Rarely in crystals like those of siderite.

Physical Characters. H., 3.5 to 4.5. Sp. gr., 3 to 3.12.

LUSTRE, dull, vitreous or silky,

OPAQUE to translucent.

STREAK, white.

TENACITY, brittle.

COLOR, white, yellow, brown.

FRACTURE, conchoidal.

BEFORE BLOWPIPE, ETC.—Infusible, becomes alkaline. With cobalt solution becomes pink. Soluble with effervescence in warm hydrochloric acid, but does not effervesce in cold dilute acid. No decided precipitate is produced by addition of sulphuric

acid, whereas heavy precipitates form with solutions of calcite and dolomite.

**SIMILAR SPECIES.**—Differs from dolomite and calcite in not yielding the calcium flame.

**REMARKS.**—Occurrences and uses as described on pp. 450, 452. Other localities in America are Bolton and Sutton, Province of Quebec, at Texas, Pa., Barehills, Md., and Bolton and Roxbury, Massachusetts, and other foreign localities, Madras, India; Hrubschütz, Moravia; Snarum, Norway; Greiner, Tyrol.

### THE BORON MINERALS.

The minerals described are :

|                |                   |                        |            |
|----------------|-------------------|------------------------|------------|
| <i>Acid</i>    | <b>Sassolite</b>  | $H_2BO_3$              | Monoclinic |
| <i>Borates</i> | <b>Borax</b>      | $Na_2B_4O_7, 10H_2O$   | Monoclinic |
|                | <b>Ulexite</b>    | $CaNaB_4O_7, 8H_2O$    |            |
|                | <b>Colemanite</b> | $Ca_2B_6O_{11}, 5H_2O$ | Monoclinic |
|                | <b>Boracite</b>   | $Mg_7Cl_2B_{10}O_{20}$ | Isometric  |

Boron is also a constituent of the silicates *tourmaline*, *datolite*, *axinite* and *danburite*, and of a number of rare borates such as *sussexite*, *howlite*, and *warwickite*.

### ECONOMIC IMPORTANCE.

The world's production\* is about 120,000 tons of crude ores, of which the United States furnishes about half in the form of *colemanite*, Chili about two fifths in the form of *ulexite* and Turkey 14,000 tons in the form of *pandermite* (colemanite). The small production of Italy (*sassolite*), Peru, Argentina and Bolivia (*ulexite*) and Germany (*boracite*) make up the rest.

In 1914 this country produced 62,400 tons, all colemanite from California.

Sassolite to the extent of two or three thousand tons yearly, is obtained by condensing and evaporating the steam issuing from fumaroles in the mountains of Tuscany.

When the crude material is borax with other sodium and calcium salts, the borax is extracted by boiling in hot water, cooling and crystallizing. The calcium borates are decomposed by sodium carbonate or sulphate to form borax, or by sulphuric or hydrochloric acid or chlorine if boric acid is first to be produced.

Commercial borax is manufactured from all the minerals men-

\* Mineral Resources U. S., 1914, p. 285.

tioned, and has important uses. Because of its power to unite with almost any oxide to form a fusible compound it is used in blowpipe analysis, assaying, soldering, brazing and welding and as a basis of enamels. Because of its cleansing qualities it is used in soaps and cleansing solutions, and because of its antiseptic qualities it is used as a food preservative, and in antiseptic powders and cosmetics.

It is a constituent of flint glass, strass, from which imitation gems are cut, and mixed with casein it forms a substance resembling gum arabic.

#### FORMATION AND OCCURRENCE OF BORON MINERALS.

Boron occurs in igneous and metamorphic rocks, contacts, and fissures as borosilicates, especially tourmaline, but also datolite, axinite and danburite. The economic deposits, however, are borates or boric acid, which appear in general to be associated with volcanic exhalations.

#### Vapors of Lagoons (Soffioni).

In certain of the steaming lagoons of Tuscany the vapors contain chiefly boric acid (*sassolite*). This is true of some other volcanic vapors, as at Vulcano, Lipari.

#### Hot Springs in Volcanic Regions.

At Sasso and Mt. Rotondo, Tuscany, are hot springs containing boric acid (*sassolite*). A copper mine\* at Boccheggiano, Tuscany, had to be abandoned because it encountered a boric acid (*sassolite*) spring at a temperature of 40° C. A hot spring at Baños del Toro, Chili, deposits calcium borate, *colemanite*,† and the hot springs of California and Nevada and Ladak Kashmer, India and the mud volcanoes of Kertch and Taman, southern Russia, deposit *borax*.

#### Old Lake Beds.

The tertiary lake beds of California yield *colemanite* in large amounts. They occur in clay and sandstone underlain by rhyolite and overlain by gypsum, limestone and debris, the largest being in a range of hills near Death Valley and the solid mineral being

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\* Beyschlag, Vogt and Krusch (Truscott), 911.

† Lindgren, "Mineral Deposits," 277.

at times in layers 15 feet thick. The Turkish deposits near Panderma, Asia Minor, similarly lie in a bed beneath gypsum.

Lindgren\* holds that during the formation of the lake beds there was also intense volcanic activity and large volumes of hot water containing boron, which in contact with limestone or solutions containing calcium produced the colemanite.

#### **Borax Lakes or Marshes.**

The original *borax* locality was the shores of the salt lakes of Tibet. In California, Nevada and Oregon borates occur, chiefly *borax* and *ulexite*, in the marshes and "playas," or shallow nearly dry lakes, probably leached from the higher *colemanite* deposits. Similar deposits, chiefly *ulexite*, occur in lagoons and troughs in Atacama and Ascotan, Chili; also in Argentina and Peru with gypsum and halite.

#### **Marine Borates.**

The borates deposited from sea water are chiefly *boracite* as at Stassfurt and the crystals in gypsum in other localities.

#### **SASSOLITE. — Natural Boracic Acid.**

COMPOSITION. —  $\text{H}_2\text{BO}_3$ , ( $\text{B}_2\text{O}_3$  56.4,  $\text{H}_2\text{O}$  43.6 per cent.).

GENERAL DESCRIPTION. — Small white or yellowish scales, of pearly lustre, acid taste, and somewhat unctuous feel. Rarely stalactitic or in minute triclinic crystals. Occurs chiefly in solution or vapor in volcanic regions.

**Physical Characters.** H., 1. Sp. gr., 1.43.

LUSTRE, pearly.

TRANSLUCENT.

STREAK, white.

TENACITY, brittle.

COLOR, white or yellowish.

TASTE, sour or acid.

BEFORE BLOWPIPE, ETC.—Fuses easily with intumescence to a clear glass without color, but colors the flame yellowish-green. In closed tube, yields water. Soluble in water.

REMARKS.—In the region of volcanoes sassolite is brought to the surface in the jets of steam, collects in the water from these jets, and, to some extent, forms also a crust more or less solid. The only productive locality is in Tuscany. It forms a small proportion of the boron compounds at the California borax localities.

#### **BORAX.—Tinkal.**

COMPOSITION.— $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ , ( $\text{B}_2\text{O}_3$  36.6,  $\text{Na}_2\text{O}$  16.2,  $\text{H}_2\text{O}$  47.2 per cent.).

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\* *Ibid.*, 282.

**GENERAL DESCRIPTION.**—A glistening, white or nearly white efflorescence or constituent of certain soils, but more frequently in solution in lakes, or as well-formed monoclinic crystals in the mud of these lakes. The crystals closely resemble those of pyroxene in form and angle.

**Physical Characters.** H., 2 to 2.5. Sp. gr., 1.69 to 1.72.

LUSTRE, vitreous to dull. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white, gray, bluish, greenish. TASTE, alkaline.

**BEFORE BLOWPIPE, ETC.**—Swells greatly and fuses to a clear glass. Colors flame yellow, and if mixed to a paste with a flux of acid potassium sulphate and powdered fluorite, and fused, it will color the flame bright green. In closed tube, swells, blackens, yields much water and a burnt odor. Soluble in water. If treated with a few drops of sulphuric acid, covered with alcohol, and the alcohol set on fire, a green flame is obtained.

**REMARKS.**—Occurs as described on p. 456, as a deposit from lakes and mud volcanoes. In the United States the deposits are mainly in Esmeralda County, Nevada, and in Lake, Bernardino and Inyo Counties, California.

### ULEXITE.—Boronatrocalcite.

**COMPOSITION.**— $\text{CaNaB}_4\text{O}_7 \cdot 8\text{H}_2\text{O}$ , ( $\text{B}_2\text{O}_3$  43.0,  $\text{CaO}$  13.8,  $\text{Na}_2\text{O}$  7.7,  $\text{H}_2\text{O}$  35.5 per cent.).

**GENERAL DESCRIPTION.**—White, rounded masses (cotton-balls) of loosely-compacted, intertwined, silky fibres, which are easily pulverized between the fingers.

**Physical Characters.** H., 1. Sp. gr., 1.65.

LUSTRE, silky. TRANSLUCENT.

COLOR and STREAK, white. TENACITY, brittle.

**BEFORE BLOWPIPE, ETC.**—Fuses very easily, with intumescence to a clear glass. Colors flame intense yellow, and will yield green flame, as with borax. In closed tube yields water. Soluble in acids.

**REMARKS.**—Occurs in dry lakes or on the banks surrounding partially dried lakes, with halite, gypsum, glauberite, borax, etc., as described on p. 456; also in small amount in the gypsum of Nova Scotia.

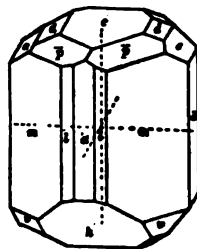
**COLEMANITE. — Priceite, Pandermite.**

COMPOSITION. —  $\text{Ca}_2\text{B}_6\text{O}_{11} + 5\text{H}_2\text{O}$ , ( $\text{B}_2\text{O}_3$  50.9,  $\text{CaO}$  27.2,  $\text{H}_2\text{O}$  21.9 per cent.).

GENERAL DESCRIPTION. — Occurs in groups of colorless transparent crystals resembling those of datolite but usually larger, and in simpler wedge-shaped forms. Also found in compact white masses like porcelain and in loosely aggregated chalk-like masses.

CRYSTALLIZATION. — Monoclinic. Axes  $a : b : c = 0.775 : 1 : 0.541$ ;  $\beta = 69^\circ 51'$ . Common faces are:  $l = (2a : b : \infty c)$ ,  $\{120\}$ ;  $v = (a : b : 2c)$ ,  $\{221\}$ ;  $e = (\infty a : b : 2c)$ ,  $\{021\}$ ;  $h = (a : \infty b : 2c)$ ,  $\{201\}$ . Usually short prismatic and highly modified. Supplement angles,  $mm = 72^\circ 4'$ ;  $mc = 73^\circ 49'$ ;  $ac = 69^\circ 51'$ .

FIG. 455.



Physical Characters. H., 4 to 4.5. Sp. gr., 2.26 to 2.48.

LUSTRE, vitreous to dull.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white or colorless.

CLEAVAGE, parallel clino-pinacoid

**Before Blowpipe, Etc.** — Decrepitates, intumesces and fuses easily to white or colorless glass, coloring the flame green. Insoluble in water, easily soluble in hot hydrochloric acid with separation of boric acid on cooling. Strongly heated with cobalt solution becomes blue.

VARIETIES. *Priceite*. — Loosely compacted white chalky masses. *Pandermite*. — Firm compact porcelain-like white masses.

REMARKS. — Priceite occurs in Curry County, Oregon, in layers between slate and steatite. Pandermite is found in a bed beneath gypsum near Panderna on the Sea of Marmora. Colemanite at Inyo and San Bernardino Counties, Cal., with celestite and quartz. Especially abundant near Daggett in the Mojave Desert.

**BORACITE. — Stassfurtite.**

COMPOSITION. —  $\text{Mg}_5\text{Cl}_2\text{B}_6\text{O}_{20}$  ( $\text{B}_2\text{O}_3$  62.57,  $\text{MgO}$  31.28,  $\text{Cl}$  7.93 per cent.).

GENERAL DESCRIPTION. — Snow-white, rather soft masses (stassfurtite) and small hard glassy isometric crystals of the hextetrahedral class, p. 62, usually showing the tetrahedron  $p$  with or without the cube  $a$  and dodecahedron  $d$ . Strongly pyroelectric.

PHYSICAL CHARACTERS. — Transparent to opaque. Lustre, vitreous. Color, white, yellowish, greenish. Streak, white. H., 7 (crystals), 4-5 (masses). Sp. gr., 2.9 to 3. Brittle.

FIG. 456.

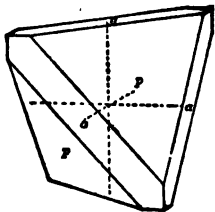
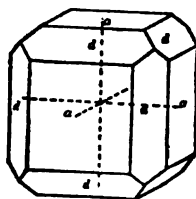


FIG. 457.



**BEFORE BLOWPIPE, ETC.**—Fuses easily with intumescence, to a white glass and colors the flame yellowish green. In closed tube yields no water or but little. Soluble slowly in hydrochloric acid. Strongly heated with cobalt solution becomes violet.

**REMARKS.**—Occurs in deposits of halite, gypsum, anhydrite, and especially in the immense beds of potassium and magnesium salts at Stassfurt, Prussia.

### MINERALS OF CHLORINE, BROMINE, IODINE, FLUORINE.

**Chlorine** occurs in the igneous basic rocks in sodalite, wernerite, chlor-apatite. It is rare in ore veins, though the chlorides of silver and mercury may occur in upper parts of deposits. The economic sources are the chlorides of the chemical sediments and brines, especially halite, carnallite, kainite, sylvite.

Halite is the usual raw material. By treatment with sulphuric acid hydrochloric acid is made and chlorine from hydrochloric acid and pyrolusite. Calcium chloride to the amount of 20,000 tons per year is recovered from brines in the U. S.

#### Bromine.

Aside from bromyrite, and embolite, and the rare iodobromite there are no recognized minerals containing bromine. The element occurs in the minerals of the chemical sediments especially at Stassfurt, Germany, where the mother liquors carry 15 to 35 per cent. Br. The brines of the Saginaw Valley in Michigan, in the Ohio Valley in Ohio and West Virginia, and in the Kanawah Valley in West Virginia contain 2 to 3 parts of bromine to 1,000 of salt, which after the crystallization of the salt, is recovered.

The production\* of bromine in the United States in 1915 was 855,857 pounds, valued at \$856,307.

Bromine is used in making the bromides for medicine and photography, and in coal-tar dyes and as a disinfectant. The recent

\* *Min. Resources, U. S., 1915, p. 276.*



large demand from abroad is said to be for making asphyxiating gas.

### **Iodine.**

There are few mineral species which contain iodine, those best known are: the iodides of silver and copper, *iodyrile* and *marshite*, and the iodate lautarite\*  $\text{Ca I}_2\text{O}_6$  found in the sodium nitrate deposits of Chili.

The great source of iodine is the mother liquor from the refining of soda niter, which may contain as much as 20 per cent. of sodium iodate. It is treated with sodium bisulphite giving solid iodine which is filtered and sublimed.

There was produced in 1913—961,336 pounds of which this country used 288,750 in the manufacture of iodoform, hydriodate and potassium iodide.

### **Fluorine.**

The fluorine minerals are connected with pneumatolytic action, contacts, pegmatites, tin and apatite veins, etc. The great minerals are fluorite, and cryolite, but it enters into various silicates such as topaz, chondrodite, lepidolite and some tourmaline and into pyrochlore, fluocerite and a series of unimportant fluorides.

The principal product is hydrofluoric acid made from fluorite (or cryolite) and used in etching glass and as a preservative.

## **THE SULPHUR MINERALS.**

The mineral described is:

|          |         |   |              |
|----------|---------|---|--------------|
| Formula. | Sulphur | S | Orthorhombic |
|----------|---------|---|--------------|

The great sulphides, pyrite, marcasite, pyrrhotite, sphalerite, galena, chalcopyrite, and many minor sulphides, sulpho salts and sulphates such as gypsum, anhydrite, barite, have already been described.

### **ECONOMIC IMPORTANCE.**

The United States consumed approximately 1,000,000 long tons of sulphur in 1913. Of this amount 32,127 tons was in the

form of gypsum. Easily

obtained from the

form of native sulphur, almost wholly obtained from Louisiana, 607,496 tons was present in pyrite from which it was burned, and 175,000 tons were recovered in sulphuric acid from the sulphides of zinc and copper during the recovery of the metals.

Deducting the sulphur from imported pyrite and brimstone and adding the exported sulphur the net sulphur produced in the United States in 1914 becomes

|                                |              |
|--------------------------------|--------------|
| Sulphur in native sulphur..... | 324,627      |
| Sulphur in pyrite.....         | 148,131      |
| Sulphur in sulphuric acid..... | 175,000      |
|                                | <hr/>        |
|                                | 647,758 tons |

Sulphur is also recovered in large quantities from the former waste products of gas works, Leblanc soda factories and other chemical works.

Nearly one half of the world's supply of native sulphur is obtained from the Island of Sicily. 338,344 long tons were produced in 1914.

Sulphur is extracted from the native mineral by simple fusion and consequent separation from the gangue. The common method in use in Sicily involves the burning of part of the sulphur to melt the remainder, causing heavy loss of the element. The crude sulphur may be refined by sublimation. Pyrite is burned directly in specially constructed furnaces, the sulphur dioxide produced being used partly as such but most of it being converted into sulphuric acid by further oxidation sometimes in lead-lined chambers with steam and nitrous fumes. Most of the sulphuric acid made is "chamber acid" of 50 Baumé used in the manufacture of fertilizers from phosphate rock, making ammonium sulphate, etc. Stronger acid is used for "pickling" steel and in the purification of petroleum and the fuming acid in the manufacture of explosives and colors.

Sulphur dioxide is concentrated and liquefied by compression and used in enormous quantities in digesting wood pulp for paper stock and as a bleaching agent for silk, straw, etc.; also in cleaning clay, as a disinfectant and many other purposes. Another large use of sulphur is in protecting grape vines from mildew, especially in France, and small amounts are utilized in the manufacture of

matches—for medicinal purposes, and in the making of gunpowder, fireworks, insecticides, for vulcanizing india rubber, etc.

#### FORMATION AND OCCURRENCE OF SULPHUR DEPOSITS.

Disregarding sulphur derived by alteration\* of sulphides, pyrite, galenite, etc.\* Sulphur deposits classify as:

##### **Sulphur from Volcanic Exhalations.**

Resulting from partial oxidation of  $H_2S$  or reaction between  $H_2S$  and  $SO_2$  given off from volcanoes and depositing in fissures and elsewhere in the crater.

The most important deposit is at Hokkaido, Japan, in walls and massive heaps in an old crater still yielding fumes. Another not yet worked is at Popocatepetl, Mexico, and a deposit exists on a volcanic island near New Zealand.† Smaller deposits exist in the Yellowstone.

##### **Deposits from Hot Springs.**

Superficial deposits due to oxidation of  $H_2S$  exist near hot springs,‡ some of which are workable, as at Cody, Wyoming; Cove Creek, Utah; Cuprite, Nevada; and Sulphur Bank, California.

##### **In Gypsum of Chemical Sediments.**

Nearly all great gypsum beds contain sulphur and nearly all great sulphur beds occur with gypsum and limestone associated with hydrocarbons, carbonates and sulphates. It is practically certain the sulphur is due to the reduction of gypsum by organic agencies.

The most important deposits are those of Sicily and Louisiana.

In Sicily the sulphur-bearing gypsum carrying 8 to 25 per cent. S is with blue gray limestone, clay, sandstone and halite. At Calcasieu, Louisiana, almost 100 feet of pure sulphur underlies clay and limestone. Other localities in which S was derived from beds of gypsum are Texas; Conil near Cadiz, Spain; Bex, Switzerland; Cracow, Poland.

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\* The pyrite in limestone of Lake Champlain sometimes yields crusts of sulphur an inch thick.

† *Mineral Industry*, 1914, p. 689.

‡ Lindgren, "Mineral Deposits," 338.

**SULPHUR. — Brimstone.**

**COMPOSITION.** — S, sometimes with traces of tellurium, selenium, or arsenic. Often mixed with clay or bitumen.

**GENERAL DESCRIPTION.** — Translucent or transparent, resinous, crystals of characteristic yellow color. Also in crusts, stalactites, spherical shapes, and powder. Sometimes brown or green.

FIG. 458.

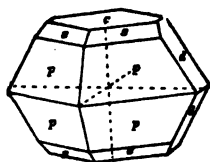
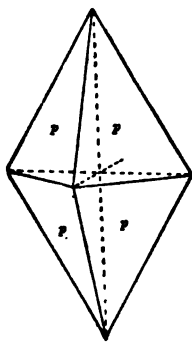


FIG. 459.



**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.813 : 1 : 1.903$ . Usually the pyramid  $p$ , sometimes modified by the base  $c$ , the pyramid  $s = (a : b : \frac{1}{3}c)$ ,  $\{113\}$ ; or the dome  $d = (\infty a : b : c)$ ,  $\{011\}$ . Supplement angles  $pp = 73^\circ 34'$ ;  $ss = 53^\circ 9'$ ;  $cd = 62^\circ 17'$ .

Optically +. Axial plane, the brachy-pinacoid. Acute bisectrix vertical. Axial angle with yellow light  $2V = 69^\circ 5'$ .

**Physical Characters.** H., 1.5 to 2.5. Sp. gr., 2.05 to 2.09.

LUSTRE, resinous.

TRANSPARENT to translucent.

STREAK, white or pale yellow. TENACITY, brittle.

COLOR, yellow, yellowish-orange, brown, or gray,

CLEAVAGE, parallel to base, prism and pyramid, not perfect.

**BEFORE BLOWPIPE, ETC.**—Melts easily, then takes fire and burns with a blue flame and suffocating odor of sulphur dioxide. In closed tube melts and yields a fusible sublimate, brown hot, yellow cold, and if rubbed on a moistened silver coin the coin is blackened. Insoluble in acids.

**REMARKS.**—Occurrence and uses, as described on p. 461-462.

## THE SELENIUM AND TELLURIUM MINERALS.

The mineral described is:

*Tellurium*

Te.

Hexagonal

Native *selenium* is not proved. *Selensulphur* is a name given to selenium-bearing sulphur from Vulcano, Lipari, Sandwich Islands and Japan. Several selenides\* occur including selenides of mercury, *tiemanite*, and *onofrite*, and selenide of lead, *clausenthalite*.

### Selenium.

Selenium in minute quantities occurs in the copper ores of Butte, Montana, and other copper regions. 22,867 pounds was recovered in 1914 from their electrolytic refining.† It is also found in the gold bullion from Tonopah, Nevada, and Redjang Lebong, Sumatra. In none of these cases have the selenium minerals been identified.

Selenium is used principally to give a red color to the glass used in signal lamps and to color enamels red. According to Roscoe and Schorlemmer‡ selenium heated for considerable time to 210° C. attains a granular condition. In this condition if exposed to diffused daylight its electric resistance diminishes instantly and on shutting off light it slowly regains it. A number of electrical inventions depend on this, such as automatic lighting and extinguishing gas buoys. Selenium cells for measuring the intensity of light have been constructed. Minor uses are in microscopic and chemical work.

### Tellurium.

Tellurium occurs plentifully§ in combination with gold, silver, mercury, lead and bismuth as the minerals calaverite, sylvanite, krennerite, hessite, petzite, nagyagite, coloradoite, tetradyomite. Oxidized products are rare."

\* Rare species, naumannite, berzelianite, lehrbachite, eucairite, sorgite, crookesite.

† Mineral Resources U. S. 1914 p. 13.

‡ Chemistry, Vol. 1, p. 402.

§ Rare tellurides are native stannite, topalpite. It has been estimated that at the Chinese Creek locality the weight of tellurium exceeds that of the gold approximately in the ratio 7 to 5, that is with a gold production of up to 1908 of \$191,830,000 there has been about 450 tons of tellurium.

Te. also combines to tellurates.

Although found in the slimes of the copper refineries there are no economic uses.

#### TELLURIUM.

COMPOSITION.—Te with a little Se, S, Au, Ag, etc.

GENERAL DESCRIPTION.—A soft tin white mineral of metallic lustre occurring fine grained or in minute hexagonal prisms.

PHYSICAL CHARACTERS.—Opaque. Lustre, metallic. Color and streak, tin-white. H., 2 to 2.5. Sp. gr., 6.1 to 6.3. Rather brittle.

BEFORE BLOWPIPE, ETC.—On charcoal fuses easily, volatilizes, coloring flame green and forming a white coat, which is made rose color by transferring to porcelain and moistening with sulphuric acid. Soluble in hydrochloric acid.

REMARKS.—Occurs at Zalathna, Siebenburgen, in sandstone, sprinkled through pyrite or alternating with it in thin layers; at the John Jay mine, Colorado, in pieces up to 25 pounds, and in California.

#### THE HYDROGEN MINERALS.

The mineral described is:

Water.

H<sub>2</sub>O.

Hexagonal.

HYDROGEN, which forms about one per cent. of the earth's crust, is a constituent of many minerals, being present in combination and as water of crystallization. It is present to a limited extent in natural gas and in volcanic gases; it escapes in combination with sulphur from many sulphur springs and, in combination with carbon, occurs as marsh gas, petroleum, ozocerite, etc.

Its compound water is everywhere in nature and the great part it plays in the formation and decomposition of minerals has been discussed, p. 244. It is a universal solvent when pure.

The uses are too well known to need summarizing even if statistics were available. The minor item of mineral waters in 1914 amounted to 54,358,466 gallons and the yearly supply of water for one great city probably exceeds in weight the yearly production of any other mineral product in the entire country.

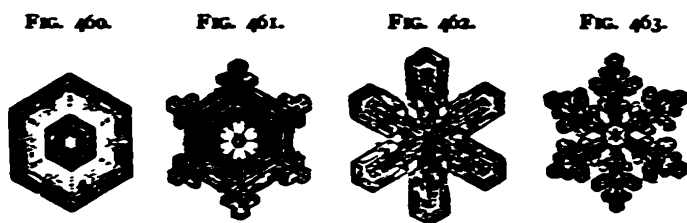
#### WATER. — Ice, Snow.

COMPOSITION.—H<sub>2</sub>O, (H., 11.1, O., 88.9 per cent.).

GENERAL DESCRIPTION.—*Ice or snow* at or below 0° C. *Water* from 0° to 100° C. *Steam* above 100° C., or aqueous vapor at all ordinary temperatures.

CRYSTALLIZATION.—Hexagonal. Axis  $c = 1.403$  approximately.

As snow, the crystals are principally compound star-like forms branching at 60° and of great diversity. Simple crystals are sometimes found as hail. Optically +.



Magnified Snow Crystals.

**Physical Characters.** H. (ice), 1.5. Sp. gr. (ice), 0.91.

LUSTRE, vitreous.

TRANSPARENT.

STREAK, colorless.

TENACITY, brittle.

COLOR, white or colorless, pale blue in thick layers.

Tasteless if pure.

**BEFORE BLOWPIPE, ETC.**—Melts at 0° C. Under pressure of 760 mm. boils at 100° C. and is converted into steam.

### THE NITROGEN MINERALS.

The two great nitrates, soda nitre and nitre, have been described and their occurrence and importance discussed. Other minor nitrates exist, one of which, nitrocalcite,  $\text{Ca}(\text{NO}_3)_2 + n\text{H}_2\text{O}$ , is not uncommon as an efflorescence in limestone caves and it is stated\* that in the war of 1812 the material from Mammoth Cave, Kentucky, was leached and converted into nitre by filtering through wood ashes. Nitrocalcite is also found in the soil of Venezuela. A few still rarer nitrates are known, such as darapskite and gerhardtite, others have been reported and nitrogen is found in uraninite.

The necessity of nitrogenous compounds for plant food and for explosives has resulted in successful attempts to fix atmospheric nitrogen by the arc† calcium cyanamide and Haber methods, and to further utilize the ammonium sulphate produced in coking

\* Merrill's "Rock-forming Minerals," p. 318.

† In the production of calcium cyanamide, coke and lime are fused together to form calcium carbide. This, when heated, is treated with pure nitrogen made at the present time by liquifying air and boiling off the oxygen. In the arc method the nitrogen and oxygen of the air are directly combined under the influence of the electric discharge. In the Haber process nitrogen and hydrogen are made to combine under pressure at elevated temperatures in the presence of some catalyzing agent.

and estimated\* as about 700,000 tons per year. A process for oxidizing this ammonia to nitric acid is still needed.

### THE PHOSPHORUS MINERALS.

The minerals described are:

|                  |   |              |
|------------------|---|--------------|
| <b>Apatite</b>   | $\text{Ca}_5(\text{Cl},\text{F})(\text{PO}_4)_3$                | Hexagonal    |
| <b>Wagnerite</b> | $\text{Mg}_2\text{PO}_4\text{F}$                                | Monoclinic   |
| <b>Wavellite</b> | $\text{Al}_3(\text{OH})_3(\text{PO}_4)_4 + 9\text{H}_2\text{O}$ | Orthorhombic |
| <b>Vivianite</b> | $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$          | Monoclinic   |

Phosphides exist in iron meteorites, but otherwise phosphorus occurs only in the form of phosphates, of which there are known about fifty, including *xenotime*, *monazite*, *pyromorphite*, *amblygonite*, *lazulite*, *variscite*, *turquoise*, *torbernite*, and *autunite*.

### ECONOMIC IMPORTANCE.

The yield of crystalline *apatite* is nearly negligible and the *phosphorite* deposits of Spain are no longer worked. There may be some recovery of such material as a by-product in the concentration of the iron ores of New York and Norway.

Practically the economic deposits are limited to *rock phosphates* and *guanos*.

In 1915 this country produced† 1,835,667 long tons of phosphate rock distributed as follows:

|                              |           |
|------------------------------|-----------|
| Florida.....                 | 1,358,611 |
| Tennessee and Arkansas.....  | 389,759   |
| South Carolina.....          | 83,460    |
| Idaho, Utah and Wyoming..... | 3,837     |

The world's production in 1913 amounted to over 6,780,000 metric tons. In 1914 there was a heavy decline to less than 4,000,000 tons.‡ This country produced over one half and the other great producers were Tunis and Algeria both working "bone" phosphates.

There is a small use for making phosphorus, but the principal use is as phosphates for fertilizers. A considerable amount is ground raw and used directly, but the greater part is converted into soluble phosphates by treatment with sulphuric acid, in which state it is more readily available as plant food.

\* Gilbert, Publication 2421 Smithsonian Inst.

† Minerals Res. U. S., 1915, advance sheets.

‡ *Mineral Industry*, 1914, p. 585.



### FORMATION AND OCCURRENCE OF PHOSPHATES.

Phosphorus is present in the crust of the earth to the amount of about one tenth of one per cent. In the form of apatite and to a much less extent monazite and xenotime it is widely distributed as minute crystals in igneous rocks.

The economic deposits may be grouped under several heads.

#### **Magmatic Segregations.**

The great apatite-iron deposits of Gellivare and K  runavaara, Norway, are magmatic segregations\* consisting of *magnetite* with considerable *fluor-apatite*.

#### **Veins.**

Veins the material of which is believed to have been pneumatically, p. 242, extracted from the neighboring gabbro by hydrochloric acid and deposited there as chlorapatite while at the same time the plagioclase of the country rock has been converted into scapolite, occur at Oeddegaden† Bamle, Norway, and along the coast at Langesund, Snarum, Arendal, etc. Associated are large crystals of wagnerite and enstatite and there is abundant rutile, ilmenite and pyrrhotite. The original gabbro contained 0.65  $P_2O_5$  1.4 to 1.5 HCl.

Similar conditions prevail‡ with the Canada veins which are in close association with a gabbro (pyroxenite). The apatite is *fluor* apatite with a little chlorine; there is no enstatite but some augite, biotite, scapolite, calcite, titanite, and ilmenite.

Apatite is a constant associate of tin veins, as at Ehrenfriedensdorf, Zinnwald, Cornwall, Devonshire, South Dakota, but is practically never in lead, silver, zinc or gold veins.

The formerly important deposits of fibrous concretionary apatite or phosphorite of Estramadura, Spain, occur in 16 foot quartz veins in clay slate in and near granite and at Jumilla,§ Spain, there is a basic eruptive of sanidine and leucite with a network of veins rich in apatite.

#### **Secondary Phosphates.**

Some of the weathering solutions due to the decomposition of apatite react with other decomposition products producing secondary phosphates.

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\* Beyschlag, Vogt and Krusch (Truscott), 173.

† *Ibid.*, 175, 453.

‡ *Ibid.*, 454.

§ Beyschlag, Vogt and Krusch (Truscott), 452.

Especially phosphates of iron and aluminum such as *Iron*. Vivianite, du-frenite, strengite, etc. *Aluminum*. Wavellite, turquoise, variscite, etc. Of these vivianite is common in bog-iron ore.

The greater portion of the phosphoric acid in the weathering solutions reaches the soil or the sea and is taken up by plant and animal organisms, from which there result beds of guano, fossil bones and marine deposits of bone, shell and animal matter, all of which may undergo further alterations.

### **Marine Sediments.**

When the marine organism dies the remains, shells, fishes bones and teeth, etc., collect in the ooze at the bottom and by relatively more rapid solution of the carbonates may form phosphate nodules or oolitic beds and if these deposits become land may be still further concentrated by further leaching out of the carbonates as in the pebble rock deposits of the coasts and rivers of North and South Carolina or may be essentially unaltered\* as in the great new deposits of Idaho and Utah where the phosphate shales and oolitic beds occur near the center of a great formation in beds 200 feet thick, or may present both stages as in western Tennessee, where there are found both brown residual phosphates due to leaching of phosphatic limestones and blue or black oolitic and shaly beds.

Other important marine deposits exist in Tunis and Algeria and the large deposits of phosphate are derived chiefly or entirely from marine deposits and are chiefly  $\text{Ca}_3(\text{PO}_4)_2$ , but are said to contain more fluorite as the geologic age increases, the purest approaching fluorapatite.

### **Guano Beds.**

Guano beds are formed by sea birds in rainless regions, as on the islands near Chili and Peru, and are sometimes 100 feet in depth and average over twenty per cent. of phosphate and even more of ammonia salts.

By leaching† some deposits have lost their ammonia salts, as at Navassa and Sombrero and others of the West Indies.

Christmas Island, Indian Ocean, is a large producer and others are in Polynesia.

### **Replacements.**

Guano‡ may furnish solutions of phosphates capable of attacking

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\* Lindgren, "Mineral Deposits," p. 260.

† Lindgren, "Mineral Deposits," p. 257.

‡ Guano contains many phosphates, some of which are acid. Clarke gives *Bulletin* 491 U. S. Geol. Survey, 496, a list of 10 species.

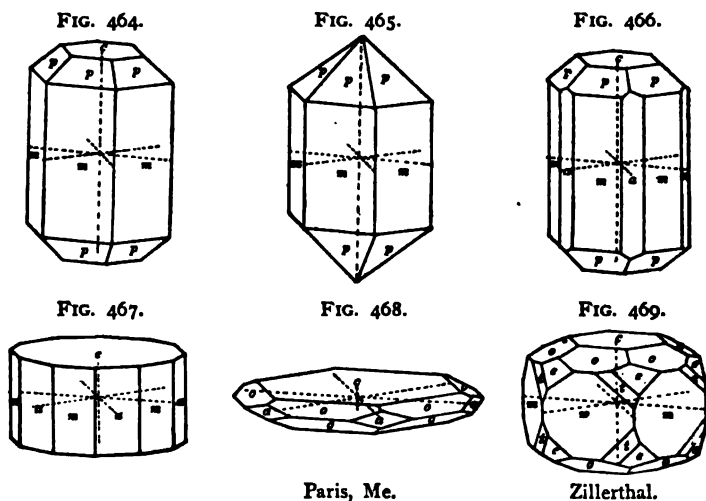
underlying rocks, forming phosphate of lime with limestone or phosphates of aluminum\* from the feldspars of igneous rocks, as in the trachyte of Clipperton Atoll, North Pacific.

Similarly the marine sediment phosphates, may be in part dissolved and replace limestone, as in the "white phosphate" of Tennessee.

### APATITE.—Asparagus Stone. Phosphate Rock.

COMPOSITION.— $\text{Ca}_5(\text{Cl.F})(\text{PO}_4)_3$ .

GENERAL DESCRIPTION.—Large and small hexagonal prisms, usually of green or red color, but sometimes violet, white or yellow. Also in compact varieties which are commonly dull-gray or white, rock-like masses or nodules not unlike common limestone.



CRYSTALLIZATION.—Hexagonal. Class 3° order pyramid, p. 57. Axis  $c = 0.735$ . Usually the unit prism  $m$  terminated by the unit pyramid  $p$  with or without the base  $c$ . More rarely the second order prism  $a$  or the flat pyramid  $o = (a : \infty a : a : \frac{1}{2}c)$ ,  $\{10\bar{1}2\}$ , Fig. 469; and occasionally third order pyramids, as  $t = (\frac{2}{3}a : 4a : a : \frac{1}{2}c)$ ,  $\{31\bar{4}3\}$ , Fig. 469.

Supplement angles:  $pp = 37^\circ 44'$ ;  $rr = 22^\circ 31'$ ;  $cp = 40^\circ 18'$ ;  $cr = 22^\circ 59'$ . Optically —, low refraction, weak double refraction.

\* A species called *minervite*, approximating  $\text{H}_2\text{KAl}_3(\text{PO}_4)_6\text{H}_2\text{O}$ , has been found in the Minerva Grotto, France, and similar material from Oran Cave, Algeria, Jenolan Cave, New South Wales. *Ibid.*, 497.

**Physical Characters.** H., 4.5 to 5. S<sub>3</sub>, gr., 3.17 to 3.23.

LUSTRE, vitreous to resinous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, green, red, brown, yellow, violet, white, colorless.

CLEAVAGE, imperfect basal and prismatic.

BEFORE BLOWPIPE, ETC.—Fuses with difficulty on sharp edges and colors the flame yellowish-red, or, if moistened with concentrated sulphuric acid, colors the flame momentarily bluish-green. Easily soluble in hydrochloric acid.

If to ammonium molybdate in nitric acid solution a few drops of a nitric acid solution of apatite be added, a bright-yellow precipitate will be thrown down on heating. In the chlorine variety silver nitrate will produce a curdy white precipitate in the nitric acid solution.

VARIETIES.—Certain mineral deposits are essentially of the same composition as crystalline apatite.

*Phosphorite*.—Concretionary masses, with fibrous or scaly structure. H = 4.5.

*Phosphate Rock*.—Approaches Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>; sometimes is only phosphatized limestone, shale, etc.; usually marine sediment.

*Guano*.—Granular to sponge-like and compact material, of gray to brown color. Sometimes with lamellar structure.

SIMILAR SPECIES.—Green crystals, differ from beryl in lustre, hardness and solubility. Red crystals differ from willemite in not gelatinizing or yielding zinc.

REMARKS.—Occurs as described on p. 468. The most famous American localities for the pure mineral are in Ontario and Quebec, Canada. Others, smaller in extent, occur at Bolton, Mass.; Crown Point, N. Y., and Hurdstown, N. J.

#### WAGNERITE.

COMPOSITION.—Mg<sub>2</sub>PO<sub>4</sub>F, P<sub>2</sub>O<sub>5</sub> 43.8, MgO 49.3, F 11.8 per cent.

GENERAL DESCRIPTION.—Cleavable masses and rough monoclinic crystals of yellow to flesh red color. H., 5 to 5.5. Sp. gr., 2.98.

BEFORE BLOWPIPE.—Fuses at 4 to greenish gray glass. With sulphuric acid gives bluish flame. In closed tube with phosphorus glass gives fluorine. Soluble in hydrochloric acid.

REMARKS.—The dominant mineral in some of the phosphate veins of Bamle, Norway.

#### WAVELLITE.

COMPOSITION.—Al<sub>2</sub>(OH)<sub>2</sub>(PO<sub>4</sub>)<sub>2</sub> + 9H<sub>2</sub>O. (Al<sub>2</sub>O<sub>3</sub> 38.0, P<sub>2</sub>O<sub>5</sub> 35.2, H<sub>2</sub>O 26.8 per cent.). F is sometimes present.

GENERAL DESCRIPTION.—Hemispherical masses which, when broken, yield complete or partial circles with radiating crystals, rarely large enough to be measured.

Occasionally stalactitic. Color most frequently white, green or yellow. H., 3.5 to 4. Sp. gr., 2.31 to 2.34.

**BEFORE BLOWPIPE, ETC.**—Whitens, swells, and splits, but does not fuse. With cobalt solution becomes deep blue. In closed tube yields acid water. Soluble in hydrochloric acid. Ammonium molybdate produces a yellow precipitate from nitric acid solutions.

**REMARKS.**—A secondary mineral chiefly in clays and fractures. In the United States is most abundant at Magnet Cove, Ark., Holly Springs, Pa., where it was used for manufacture of phosphorus, and Silver Hill, N. C.

Foreign localities are Barnstaple, Devonshire; Dillenburg, Nassau; Cerhovic, Bohemia.

#### VIVIANITE.—Blue Iron Earth.

**COMPOSITION**— $\text{Fe}_2(\text{PO}_4)_3 \cdot 8\text{H}_2\text{O}$ . (FeO 43.0,  $\text{P}_2\text{O}_5$  28.3,  $\text{H}_2\text{O}$  28.7 per cent.).

**GENERAL DESCRIPTION.**—Usually found as a blue to bluish green earthy mineral, often replacing organic material as in bones, shells, horn, tree roots, etc. Also found as glassy crystals (monoclinic), colorless before exposure, but gradually becoming blue.

**PHYSICAL CHARACTERS.**—Transparent to opaque. Lustre, vitreous to dull. Color and streak, colorless before exposure, but usually blue to greenish. H = 1.5 to 2. Sp. gr. = 2.58 to 2.69. Brittle.

**BEFORE BLOWPIPE, ETC.**—Fuses easily to a black magnetic mass and colors flame pale bluish-green, especially after moistening with concentrated sulphuric acid. In closed tube yields water. Soluble in hydrochloric acid. The dried powder is brown.

**REMARKS.**—Common with bog iron ore. Occurs earthy in peat moss as in Shetland or near tree roots, or with horns of the elk, Isle of Man, as crystals with pyrrhotite (Bodenmais) or pyrite (Cornwall), or radiating aggregates often within fossil shells (Crimea and Mullica Hill, N. J.).

### THE CARBON MINERALS.

The more definite minerals described are:

|           |                              |           |
|-----------|------------------------------|-----------|
| Graphite  | C                            | Hexagonal |
| Osocerite | $\text{C}_8\text{H}_{20-22}$ |           |

In addition to these there are a large number of gaseous, liquid and solid carbon compounds, of economic importance which are on the border line of mineralogy, occurring naturally but being generally without definite composition or crystalline form. Among these the following are briefly described: PETROLEUM, ASPHALT, MINERAL COAL, COPALITE, and AMBRITE.

Other carbon minerals elsewhere described are diamond, and amber. Carbon also exists in enormous quantities in the mineral carbonates such as calcite, dolomite, magnesite, cerussite, siderite, and aragonite and in a number of hydrocarbons, chiefly paraffins and resins, some of which are very definite in composition and may even be crystalline, but are economically unimportant such as

|             |                               |                    |
|-------------|-------------------------------|--------------------|
| Scheererite | $\text{CH}_4$                 | Monoclinic         |
| Hatchettite | $\text{C} : \text{H} = 1 : 1$ | Sometimes crystals |
| Fichtelite  | $\text{C}_5\text{H}_8$        | Monoclinic         |
| Hartite     | $\text{C}_{12}\text{H}_{20}$  | Monoclinic         |

**ECONOMIC IMPORTANCE.**

From this standpoint the carbon minerals surpass all others both in quantities used and values. Of the \$2,114,946,024 valuation placed upon the mineral products of the United States, for 1914 \$895,615,858 are for coal and petroleum, an amount exceeding the combined value of the production of all the metals.

**Graphite.**

In 1915 the output of crystalline graphite in the mines of this country was 3,537 tons.\* Amorphous graphite to the extent of 1,181 tons—was also produced. The total product of the world is over 100,000 tons annually, obtained mainly from Ceylon and Austria, of which 13,821 tons was imported into the United States in 1915.

About one half the graphite is used in the making of crucibles, the dust and the amorphous material are used chiefly for stove polish, foundry facings and paints, and the other large uses are electrical purposes, making lead pencils and lubricants. Minor uses are in electrotyping and in protecting various products against moisture, especially gunpowder, but also tea leaves, coffee beans, and even fertilizers.

**Ozocerite** is mined in Hungary and Utah and in 1914 the United States imported† over 4,000 tons but mined none. In the crude state it serves as an insulator for electric wires. By distilling it yields: a refined product, ceresine, used for candles, waxed paper and hydrofluoric acid bottles; burning oils; paraffine; a product with properties and appearance of vaseline; and a black residuum which in combination with india rubber constitutes the insulating material called *okonite*.

**Petroleum.**

The production of crude petroleum in the United States in 1914 was 265,762,535‡ barrels. The world's production was 400,483,489 barrels. This country therefore producing over 66 per cent. of all while Russia produced less than 17 per cent. and no other country except Mexico (5.29 per cent.) as much as five per cent.

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\* Mineral Resources U. S., 1915, p. 82.

† Mineral Resources U. S., 1914, p. 356.

‡ Mineral Industry, 1914, p. 568.

Large amounts of petroleum in the crude state and all the distilled heavy oils for which there is no market are used as "fuel oils" and a smaller amount of special oils for lubricating purposes. Its chief value is due to its distillation products, mainly kerosene. Other valuable products arising from distillation of this crude oil are gasoline, naphtha,\* benzene. Various products such as lubricating oils, vaseline and paraffine are made from the residuum after the burning oils have been distilled off.

### Asphalts.

This country produced† and manufactured from petroleum in 1915 740,254 tons of asphalt as follows:

|                                    |         |
|------------------------------------|---------|
| Bituminous rock . . . . .          | 44,329  |
| Gilsonite and Wurtzilite . . . . . | 20,559  |
| Grahamite . . . . .                | 10,863  |
| Manufactured asphalt . . . . .     | 664,503 |

In addition to which it imported chiefly from Trinidad and Venezuela, 180,689 tons of asphalt.

The world's production is probably about 400,000 tons of asphalt and 600,000 tons of bituminous rock, Trinidad and Venezuela furnishing over one half of the former and France and Italy most of the latter.

The principal use is for pavements of streets and roads, mixed with sharp sand, limestone, and a little coal-tar residuum. They are also used as cement, roofing and floor material, as a paint and waterproofing for wood or metal, for insulating electric wires, and as an adulterant and coloring material in rubber goods. Manjak and gilsonite are important constituents of black varnishes. A product called "ichthyol" is used externally and internally in medicine, derived from a bituminous rock full of fossil fish at Seefeld, Tyrol.

### Fossil Resins.

The fossil resins copalite and ambrite do not occur in the United States. They are oxidized hydrocarbons much resembling ordi-

\* Gasoline is also obtained from natural gas. In 1914 to the amount of 42,652,632 gallons with little loss in the value of the gas. The natural gas yield in 1914 was valued at \$94,115,524. It consists essentially of marsh gas, but also contains hydrogen, nitrogen and some other gases, and is used in immense quantities as a fuel and, after being enriched, for illuminating purposes, and is also burned to produce lamp black.

† Resources U. S., 1915, p. 140.

nary resin in appearance, and are extensively used in varnishes and japans.

### Mineral Coal.

The world's production of mineral coal in 1914 was 1,226,330,612 metric tons, of which three countries produced 86 per cent. as follows:

|                    |             |                 |
|--------------------|-------------|-----------------|
| United States..... | 517,285,050 | or 47 per cent. |
| Great Britain..... | 292,047,544 | " 24 " "        |
| Germany.....       | 191,511,154 | " 15 " "        |

The estimated production in the U. S. for 1915 is 518,000,000 tons.

### FORMATION AND OCCURRENCE OF THE CARBON MINERALS.

With the exception of diamond and some varieties of graphite the carbon minerals are of undoubted organic origin, due to former plant and animal life. Graphite is not necessarily so, as is proved by its presence in meteorites and cast iron.

### Separation from Magma.\*

Graphite occurs in the Disco Island iron, p. 266, which contains up to four per cent. of carbon, partly as graphite. It occurs also in pegmatites and nepheline syenites.

### Metamorphosed Sediments.

Graphite results from the alteration of the carbonaceous matter in the sediment. Occurrences are numerous both of flake or crystallized graphite as in Alabama and Pennsylvania, and of the so-called amorphous graphite as in California. Considerable graphite is found in the famous Witwatersrand conglomerate and is said to be of later formation, sometimes replacing the quartz.

### Contacts.

GRAPHITE resulting from the intrusion of igneous rocks may be of definitely organic origin as in the case of the altered coal beds, at Raton, New Mexico; Sonora, Mexico, and Styria, in which the intermediate stages from coal to graphite are present.

In other instances it is attributed to magmatic exhalations, for instance:

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\* *Mineral Industry*, 1914, p. 131.

† Lindgren, "Mineral Deposits," p. 699. Beyschlag, Vogt and Krusch (Truscott), p. 1161.



"The graphite gneiss of Passau contains the mineral as a secondary impregnation only at the contact with granite"\* and speaking of the graphites of Quebec "The conclusion is justified that they were developed by igneous emanations shortly after the close of intrusive activity."†

Contacts occur also at Ticonderoga.

### Veins.

Graphite occurs in veins in igneous rocks and the surrounding sediments, as at Ceylon, in fine-grained gneiss intruded by granites and pegmatites. Dillon, Montana, along contact of pegmatitic granite with schists and limestone. Near Ticonderoga, New York, in similar contact. The Alibert mines of Irkutsk, Siberia, in nepheline syenite. The Borrowdale, Cumberland, in porphyry.

The origin is puzzling and variously ascribed to igneous exhalations,‡ infiltration of liquid hydrocarbons and subsequent metamorphism and to gaseous compounds derived from the adjoining sediments.§

It is of interest that graphite occurs in considerable quantity in the silver veins of Silver Islet|| and to a less extent in the silver veins of Temiskaming.

### Sedimentary.

Mineral coal, asphaltum, petroleum and ozocerite are all of organic origin. The coals are sediments from wood grown in place or carried there by currents, the petroleum and asphalt are chiefly found in clay shales, sands, sandstones and limestones and the ozocerite is a derivative of petroleum.

## GRAPHITE. — Plumbago, Black Lead.

COMPOSITION.—C. Sometimes with iron, sand, clay, etc.

GENERAL DESCRIPTION.—Disseminated flakes or scaly to compact masses, and more rarely six-sided plates. Soft, greasy and cold to the touch; black to very dark gray in color and usually metallic in lustre. When impure it is apt to be slaty or earthy.

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\* Weinschenck, "Grundzüge der Gesteinskunde," p. 319.

† Lindgren, "Mineral Deposits," p. 704.

‡ "Grundzüge der Gesteinskunde," p. 319, 320.

§ Lindgren, "Mineral Deposits," p. 700.

|| Beyschlag, Vogt & Krußch (Truscott), p. 669.

**Physical Characters.** H., 1 to 2. Sp. gr., 2.09 to 2.25.

|                                       |                            |
|---------------------------------------|----------------------------|
| LUSTRE, metallic to dull.             | OPAQUE.                    |
| STREAK, dark-gray.                    | TENACITY, scales flexible, |
| COLOR, black or dark gray.            | slightly sectile.          |
| CLEAVAGE, basal, cleaves into plates. | UNCTUOUS, marks paper.     |

**BEFORE BLOWPIPE, ETC.**—Infusible, but is gradually burned. May react, if impure, for water, iron and sulphur. Insoluble in acids. If a piece of graphite is brought into contact with a piece of zinc in a solution of copper sulphate, it is quickly copper-plated. Molybdenite under the same test is very slowly plated.

**SIMILAR SPECIES.**—Differs from molybdenite in darker color, streak, flame test and salt of phosphorus bead, and as above mentioned. Micaceous hematite is harder and has a red streak.

Graphite is distinguished from amorphous carbon by treatment with strong oxidizing agents ( $\text{KClO}_3$  and  $\text{HNO}_3$ ), by which it is converted into graphitic acid,  $\text{C}_{11}\text{H}_4\text{O}_6$ , a yellow transparent substance.

**REMARKS.**—The occurrence and uses have been described on pp. 475 and 473.

#### OZOCERITE OR MINERAL WAX.

**COMPOSITION.**—Closely C., 85.5, H., 14.5, per cent. Essentially one of the higher members of the paraffin series,  $\text{C}_n\text{H}_{2n+2}$ .

**GENERAL DESCRIPTION.**—Resembles wax in appearance and consistency, usually brown to nearly black and foliated, sometimes with greenish opalescence, which it imparts to its solutions. H., about 2. Sp. gr., 0.93 to 0.95.

**BEFORE BLOWPIPE, ETC.**—Melts at  $51^\circ$  to  $63^\circ$  C. Soluble in ether, naphtha or turpentine, partially soluble in boiling alcohol.

**REMARKS.**—Ozocerite is regarded as a derivative of petroleum. Originally found in Slanik, Moldavia, then in larger quantities in Boryslaw, Galicia, and Emery and Uinta Counties, Utah; Baku, Persia, and other localities.

**PETROLEUM.**—A mixture of liquid hydrocarbons. The American oils consist essentially of hydrocarbons of the paraffine series,  $\text{C}_n\text{H}_{2n+2}$ , with smaller amounts of the series  $\text{C}_n\text{H}_{2n}$  and  $\text{C}_n\text{H}_{2n-4}$ . The Russian oil, obtained mainly from Baku, on the Caspian, and the oils from Rangoon, Galicia, are different in character, consisting mainly of the naphthenes  $\text{C}_n\text{H}_{2n}$ , and do not yield as much illuminating oil on distillation.

The German petroleum is intermediate and the Canadian is rich in the solid paraffins.

**GENERAL DESCRIPTION.**—It varies from a light easily flowing liquid to a thick viscous oil. Usually dark brown or greenish in color with a distinct fluorescence. Sp. gr., 0.6 to 0.9.

**REMARKS.**—Occurs usually in clay, shales, sands, sandstones and limestones and in cavities to which it has penetrated from the adjoining rocks.

**ASPHALTUM OR MINERAL PITCH.**—Mixtures of different hydrocarbons and their oxidized products.

**GENERAL DESCRIPTION.**—Varying from thick, highly viscous liquids to solids, generally black in color and with a pitch-like luster. Melt usually from 35° to 40° C. and burn easily with a pitchy odor and bright flame. They are slightly heavier than water. Trinidad. Sp. gr., 1.28.

**REMARKS.**—Asphaltum includes the true ASPHALT of the famous pitch lakes of Trinidad and of Bermudez, Venezuela and the Dead Sea; the MANJAK of Barbadoes; the elastic ELATERITE of Derbyshire, England; the ALBERTITE of New Brunswick; the GILSONITE and WURTZILITE of Utah, the GRAHAMITE of Oklahoma. Besides these sandstone and limestone impregnated with asphalt occur.

#### MINERAL COAL.

**GENERAL DESCRIPTION.**—Mineral coal is a compact massive material of black or brownish black color and submetallic to earthy lustre. It is without crystalline structure or cleavage and has a conchoidal fracture. H., 0.5 to 2.5. Sp. gr., 1. to 1.8.

**BEFORE BLOWPIPE, ETC.**—Infusible but burns and may become pasty and in closed tube yield oily and tarry materials. Insoluble in acids, alcohol, ether, etc.

**VARIETIES.**—The entire series would range from peat to anthracite. Kemp giving\* as typical compositions

|                      | C  | H   | O   | N     |
|----------------------|----|-----|-----|-------|
| Woody tissue.....    | 50 | 6   | 43  | 1     |
| Peat. ....           | 59 | 6   | 33  | 2     |
| Lignite.....         | 69 | 5.5 | 25  | 0.8   |
| Bituminous coal..... | 82 | 5   | 13  | 0.8   |
| Anthracite.....      | 95 | 2.5 | 2.5 | trace |

The differences in appearance are great, ranging through the brown spongy peat, the brownish black lignite, the compact brown to black bituminous and the bright submetallic black anthracite.

**COPALITE** or Highgate Resin from the London blue clay and copal found in the soil of the African coast are pale yellow to gray or dirty brown resins. H., about 3. Sp. gr., 1.01. Giving aromatic odor when broken. It is soluble with difficulty in alcohol and turpentine and is very valuable for varnishes.

**AMBRITE OR DAMMAR.**—A fossil resin from New Zealand resembling Kauri gum of the same locality and of the East Indies, the Moluccas and from New Zealand. It is not so hard as copal but is harder than resin. It is a valuable basic constituent of varnishes. The New Zealand dammar is almost wholly fossil

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\* "Hand-book of Rocks," p. 104.

## CHAPTER XX.

### SILICA AND THE ROCK-FORMING SILICATES.

The order of discussion is by groups of chemically or genetically related species. The economic discussion begins the chapter but the discussions of Formation and Occurrence and of Optical Determination precede the individual groups.

#### ECONOMIC IMPORTANCE.

Aside from the occasional occurrence of certain silicates in specimens suitable for gems, only a few of this greatest group of common minerals are of economic importance as distinct minerals.

#### The Quarry Industry.

The great stone or quarry industry\* represents in the United States a capital of over \$125,000,000, and produced in 1914 material worth in the rough over \$77,000,000, and consists in the extraction of blocks of either limestone and marble or of silica and silicates. The values of silicate rocks quarried in this country were:

|                               |              |
|-------------------------------|--------------|
| Granite.....                  | \$20,028,910 |
| Basalt and Related Rocks..... | 7,865,998    |
| Sandstone.....                | 7,501,808    |
| Bluestone.....                | 1,086,699    |
| Slate.....                    | 5,706,787    |

GRANITE, commercially speaking, includes a number of hard, durable rocks, such as granite proper, syenite, gneiss, schist, diorite, and andesite, which are composed of silicates—usually three or more—and principally quartz, the feldspars and the micas, pyroxene and amphibole. It is used in enormous quantities in buildings, in paving blocks and in construction of bridges and dams, monumental work, flagstones and curbstones, crushed stone, etc.

BASALT and the related rocks include basalt, diabase and other

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\* The facts and figures are taken from *Mineral Resources of the U. S.*, 1914 and 1915.

dark igneous rocks similar in composition and properties. Their uses are chiefly as crushed stone for roads, railroad ballast and concrete.

SANDSTONE is composed of grains, chiefly quartz, with a little feldspar, mica or other minerals, and is classified as siliceous, ferruginous, calcareous or argillaceous, according to the nature of the cement which binds the grains together. Its uses are the same as those of granite, but a larger proportion of the quantity quarried is used in building.

BLUESTONE is a very hard, durable, fine-grained sandstone, cemented together with siliceous material. It is used principally for flag and curb stone.

SLATE is used chiefly as roofing material and for interior work, such as blackboards, table tops, sinks, etc. Small amounts are ground for mineral paint.

The production of silica or other silicates for economic purposes in the United States in 1915 was valued at over \$31,000,000 and may be summed up as:

|  | Short Tons. | Value.     |
|--|-------------|------------|
| Quartz.....  | 112,575     | \$ 273,553 |
| Infusorial earth and Tripoli.....  |             | 611,021    |
| Feldspars.....   | 113,769     | 629,356    |
| Micas.....   | 4,236       | 428,769    |
| Garnets.....   | 4,301       | 139,584    |
| Asbestos (amphibole and serpentine).....   | 1,731       | 76,952     |
| Talc and soapstone.....  | 186,891     | 1,891,582  |
| Clays* (kaolinite, etc.).....  | 2,209,860   | 3,756,568  |
| Fuller's earth (kaolinite, etc.).....  | 47,901      | 489,219    |
| Sand (chiefly quartz).....   | 95,461      | 386,261    |
| Millstones, Buhrstones, grindstones.....   |             | 816,134    |
| Sand and gravel for building, glass making,<br>molding, paving, grinding, etc..... | 76,603,303  | 23,121,617 |

#### Individual Minerals or Groups.

QUARTZ is used in large amounts in the manufacture of sand-paper, porcelain, pottery, glass, honestones, oilstones, and as a flux. Other large uses are as a wood filler and in paints, scouring soaps, the making of carborundum and ferro-silicon. Fused quartz is used for chemical apparatus, and colored and chalcidonic varieties are used as semi-precious or ornamental stones.

\* 1914. Clay products in 1915 were valued at \$37,325,388 of which "white ware products" and "sanitary products" represented about two thirds.

INFUSORIAL EARTH and TRIPOLI are calcined and made into water filters, polishing powders, soap filling and boiler and steam-pipe covering.

FELDSPAR is crushed in large quantities for admixture with kaolin in the manufacture of porcelain and chinaware, chiefly to form the glaze, but partly mixed with the kaolin and quartz in the body of the ware. It is also used in enamel brick and tile, and as binder for emery and corundum wheels. The purest is used in the manufacture of artificial teeth.

For AMPHIBOLE see Serpentine.

THE MICAS, especially muscovite and phlogopite, have become of great importance as non-conductors in electrical apparatus, and are also used in stove and furnace doors. The larger sheets are cut and split to the desired size; the waste is, to some extent, built up into plates suitable for certain grades of electrical work, and for covering steam boilers and pipes. Large amounts of formerly wasted material are now ground and used for decorative interior work, to ornament porcelain and glassware, to spangle wall paper, in calico printing, as a lubricant and more recently as an absorbent of nitro-glycerine and in the manufacture of certain smokeless powders.

BIOTITE bronzed by heating is used for decorative purposes and lepidolite in glass making.

GARNET is ground for an abrasive.

SERPENTINE is to some extent mined and used as ornamental stone, but is commercially classed with the marbles. The fibrous varieties of both amphibole and serpentine are known commercially as asbestos, and are extensively made into yarns, ropes and paper for fire-proof purposes, boiler and steam-pipe covering, piston packing, theatre curtains, firemen's suits. It is also used for fire-proof paints and cements, and for lining safes. Asbestos of long fine fiber is used in the laboratory as a filtering medium.

FIBROUS TALC and compact talc, or soapstone, are extensively used, the former for grinding to "mineral pulp," used in paper manufacture, the latter for many purposes, usually because it is refractory, expands and contracts very little, retains heat well and is not attacked by acids. These properties make it valuable in

furnaces, crucibles, sinks, baths, hearths, electrical switch boards and cooking utensils. Talc is also used in cosmetics, refractory paints, slate pencils, crayons, gas tips, as a lubricant and in soap making.

CHLORITE is ground and used in hard rubber, rubber tires, foundry facings, etc.

KAOLINITE AND CLAY.—Enormous and varied industries use as their raw material the beds of clay which result from the decomposition of the feldspars and other silicates. These beds are composed in part of some hydrous aluminum silicate such as kaolinite, but usually with intermixed quartz, mica, undecomposed feldspar, oxides and sulphides of iron. Their properties and uses depend chiefly upon their composition.

The clay industries include the manufacture of common brick, paving brick, fire-brick, and hydraulic cement, all varieties of earthenware, stoneware and porcelain, terra cotta, sewer pipes and drain tiles, and are carried on all over the country and the world.

FULLERS EARTH, a kind of clay, is used in the refining and clarifying of mineral oils, and for bleaching lard and cottonseed oils.

THE OTHER SPECIES AND GROUPS aside from a limited use of transparent or brightly colored material as precious or ornamental stone can not be said to have present economic importance.

### SILICA.

The minerals described are:

|            |                                     |           |
|------------|-------------------------------------|-----------|
| Quartz     | SiO <sub>2</sub>                    | Hexagonal |
| Chalcedony | SiO <sub>2</sub>                    |           |
| Tridymite  | SiO <sub>2</sub>                    | Hexagonal |
| Opal       | SiO <sub>2</sub> .nH <sub>2</sub> O |           |

Various other names have been given, some based on optical differences as *quartzine*, *lussatite*, *pseudochalcedony*, *lulecite*, some on specific gravity as *granulina* and *jenzschite*. Of them all *crystalbaltite* is best characterized and apparently represents the form which silica takes if formed at high temperatures.

### FORMATION AND OCCURRENCE OF SILICA.

According to experiments silica by slowly increasing temperatures passes through the various conditions of  $\alpha$  quartz,  $\beta$  quartz, tridymite and crystalbaltite.

$\alpha$  quartz is ordinary quartz like that of mineral veins at ordinary\* temperatures. If heated above 575° C. it develops the characteristic etch figures of  $\beta$  quartz (quartz of the granites and porphyries). It is unstable† above 800° C., tending to pass into tridymite above 800° C. and into cristobalite at 1,470°.

The occurrences may be grouped as:

#### **Crystallization from Magma.**

Quartz as the youngest constituent of granites, rhyolites and quartz porphyries and as a less important constituent of syenite and some basic igneous rocks.

*Tridymite* chiefly in volcanic rocks trachyte, rhyolite, and andesite.

#### **Pegmatites.**

*Quartz* in enormous crystals. Dakota, Maine, Connecticut, Norway, etc.

#### **Veins.**

*Quartz* both as chief gangue of ore veins and alone.

*Chalcedony, opal* and *fine grained mixtures* as later constituents.

#### **Sediments.**

*Mechanical Sediments.*—*Quartz* as chief part of sand and sandstone and important part of shale. *Tripoli* results from leaching out of calcareous material from siliceous limestone as in S. E. Missouri.

*Chemical Sediments.*—*Opal, chalcedony* and *sometimes quartz* by hot springs and from the colloidal silica formed by weathering.

*Sediments due to Organisms.*—*Diatomaceous Earth.* Microscopic water plants, called diatoms, build silica into their cells. Their remains accumulate both in salt and fresh water, forming beds. The Richmond beds from the Chesapeake to Petersburg, Virginia, are in parts 30 feet thick. The Bilin, Bohemia, beds are 14 feet thick. Other large deposits exist near Socorro, New Mexico and Nevada.

#### **Metamorphic Rocks.**

As quartzite, quartz schist and an essential constituent of other rocks partly primary, partly secondary.

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\* Am. Jour. Sci. 4S, 28, 293.

† *Ibid.*, 22, 276.



## THE OPTICAL DETERMINATION OF THE SILICAS.

|                 |            | $\gamma$ | $\epsilon$ | $\gamma - \epsilon$ |
|-----------------|------------|----------|------------|---------------------|
| QUARTZ.....     | Uniaxial + | 1.553    | 1.544      | 0.009               |
| CHALCEDONY..... | Biaxial -  | 1.537    |            |                     |
| TRIDYMIT.....   | Biaxial +  | 1.477    |            | 0.002               |
| OPAL.....       | Isotropic  | 1.446    |            |                     |

## In Thin Sections.

*Quartz*.—Usually fresh unweathered and without definite shape. Low relief, smooth surface. Interference colors gray or first order yellow. Basal sections dark between crossed nicols and with convergent light giving uniaxial cross and sometimes one ring red on outer edge, blue on inner. Circularly polarizing. Basal sections 1 mm. thickness turn the plane of polarization for yellow light  $21.7^\circ$  to right or left.

*Chalcedony*.—Between crossed nicols radial and parallel fibres, each of which has parallel extinction, and negative elongation. If spherulitic may show dark cross.

*Tridymite*.—Tile-like aggregates with strong relief and rough surface. Hardly noticeable birefringence. With crossed nicols and convergent light distorted biaxial figure. (Uniaxial at  $130^\circ$  C.)

*Opal*.—Shapeless with strong relief, rough surface and dark between crossed nicols or may show double refraction and even a negative cross (hyalite) as result of strain.

## QUARTZ.—Rock Crystal, Amethyst.

COMPOSITION.— $\text{SiO}_2$ , (Si 46.7, O 53.3 per cent.).

GENERAL DESCRIPTION.—A hard, brittle mineral which is best known in transparent, glassy, hexagonal crystals, colorless, and as

FIG. 470.

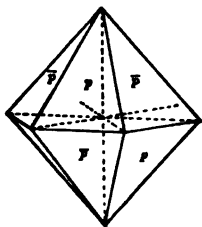


FIG. 471.

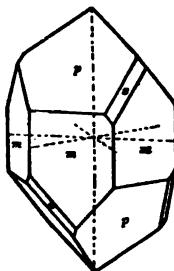
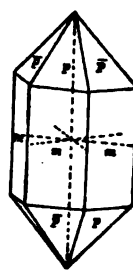


FIG. 472.



the somewhat greasy lustred, shapeless, transparent mineral of granite and other igneous rocks. Colorless if pure, but often yellow, violet, or smoky and more rarely other colors.

CRYSTALLIZATION.—Hexagonal. Class of trigonal trapezohedron, p. 55. Axis  $c' = 1.0999$ . Usually a combination of unit

FIG. 473.

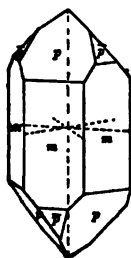


FIG. 474.

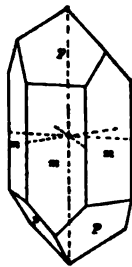


FIG. 475.

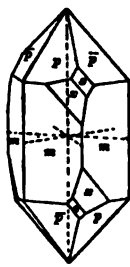
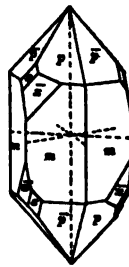


FIG. 476.



prism  $m$  with one or both unit rhombohedra,  $p$  and  $\bar{p}$ , the former often larger and brighter, and the prism faces nearly always horizontally striated. The second order pyramid  $s = (2a : 2a : a : 2c)$ ;  $\{11\bar{2}1\}$ ; frequently occurs and rarely the trapezohedral faces  $x = (\frac{2}{3}a : 6a : a : 6c)$ ,  $\{51\bar{6}1\}$ ; either right, Fig. 475, or left, Fig. 476. Supplement angles  $pp = 85^\circ 46'$ ;  $mp = 38^\circ 13'$ ;  $ms = 37^\circ 58'$ ;  $mx = 12^\circ 1'$ .

Twinned crystals are not rare. See page 68.

**Physical Characters.** H., 7. Sp. gr., 2.65 to 2.66.

LUSTRE, vitreous to greasy.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle to tough.

COLOR, colorless and all colors.

CLEAVAGE, difficult, parallel to rhombohedron.

**BEFORE BLOWPIPE, ETC.**—Infusible. With soda, fuses with marked effervescence to a clear or opaque bead, according to the proportions used. Insoluble in salt of phosphorus and slowly soluble in borax. Insoluble in all acids except hydrofluoric.

#### VARIETIES.

Rock-forming quartz is colorless or slightly cloudy or rose tinted, the quartz of ore veins is frequently amethystine. The principal varieties, which are discussed more at length under quartz as a semi-precious stone, p. 567, are

*Rock Crystal*.—Pure, colorless or nearly colorless quartz.

*Amethyst*.—Purple to violet and shading to white. Fracture shows lines like those of the palm of the hand. Color disappears on heating, and is probably due to a little manganese.

*Rose Quartz*.—Light-pink or rose-red, becoming paler on long exposure to light. Usually massive. Colored by titanium or manganese.

*Yellow Quartz* or *False Topaz*.—Light yellow.

*Smoky Quartz*.—Dark yellow to black. Smoky tint, due to some carbon compound.

*Milky Quartz* or *Greasy Quartz*.—Translucent. Usually massive. Common as a rock constituent.

*Ferruginous Quartz*.—Opaque, brown or red crystals, sometimes small and cemented like a sandstone.

*Aventurine*.—Spangled with scales of mica, hematite or goethite.

*Cat's Eye*.—Opalescent, grayish-brown or green quartz with included parallel fibers of asbestos.

REMARKS.—The formation of quartz is discussed on p. 483, and its uses, p. 480. Localities are infinite in number, a few famous ones being Switzerland; Japan; Carrara, Italy; Herkimer Co., New York; Hot Springs, Arkansas; Alexander Co., North Carolina.

#### CHALCEDONY.

COMPOSITION.—Silica with occasionally a little water.

GENERAL DESCRIPTION.—Bluish gray or translucent material in mammillary linings of cavities and concretions. Lustre like wax. Grades into more highly colored and more opaque varieties. H., 6.5 to 7. Sp. gr., 2.62 to 2.64.

CRYSTALLIZATION.—Never in crystals visible to the naked eye but under the microscope with crossed nicols is seen to be composed of minute radiating needle crystals.

VARIETIES.—Optically distinct from quartz. The color-names such as *Agate*, *Carnelian*, *Sard*, *Onyx*, *Sardonyx*, *Chrysoprase*, *Bloodstone*, are discussed on p. 572.

Other very common materials are essentially chalcedony, such as

*Flint*.—Smoky-gray to nearly black, translucent nodules, found in chalk-beds.

*Jasper*.—Opaque and containing considerable amounts of iron, and alumina, and often highly colored, as red, brown, or yellow.

*Touchstone*.—Velvet-black and opaque, on which metal streaks are easily made and compared.

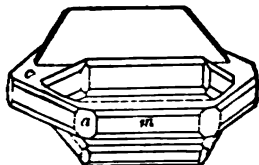


FIG. 477.

#### TRIDYMITE.

COMPOSITION.— $\text{SiO}_2$ .

GENERAL DESCRIPTION.—Small, colorless, hexagonal plates. Often in wedge shaped groups of two or three, Fig. 477. Usually prism and base sometimes pyramidal faces from which  $\epsilon = 1.6304$  calculated.

**PHYSICAL CHARACTERS.**—Transparent. Lustre, vitreous. Color, colorless or white. Streak, white. H., 7. Sp. gr., 2.28 to 2.33. Brittle.

**BEFORE BLOWPIPE, ETC.**—Like quartz, but soluble in boiling sodium carbonate.

## OPAL.

**COMPOSITION.**— $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ , ( $\text{H}_2\text{O}$ , 5 to 12 per cent.).

**GENERAL DESCRIPTION.**—Colorless, white and many colored "veins" and incrustations with internal color reflections. More often without "opalescence" but translucent and with wax-like to porcelain-like lustre. Also free masses of rounded, kidney, stalactitic and other shapes often dull or pumice-like. Colorless masses like drops of melted glass and clay like or chalky beds.

**CRYSTALLIZATION.**—No crystalline structure is evident and apparently opal is "amorphous" in the most complete sense.

**Physical Characters.** H., 5.5 to 6.5. Sp. gr., 2.1 to 2.2.

LUSTRE, vitreous, pearly, dull. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, colorless and all colors.

**BEFORE BLOWPIPE, ETC.**—Infusible. Becomes opaque and yields more or less water. Soluble in hydrofluoric acid more easily than quartz and soluble in caustic alkalies.

### VARIETIES.

*Precious and Fire Opal.*—With play of colors.

*Common or Semi-Opal.*—Translucent to opaque, with greasy lustre and of all colors, but without play of colors.

*Hyalite.*—Colorless transparent masses resembling drops of melted glass or of gum arabic.

*Geyserite, Siliceous Sinter.*—Loose, porous opal silica deposited from hot water. Opaque, brittle and often in stalactitic or other imitative shapes. *Pearl Sinter.*—Pearly, translucent material found in volcanic tufa and near hot springs is similar.

*Diatomaceous or Infusorial Earth.*—Massive, chalk-like or clay-like material composed of the remains of diatoms.

*Tripoli.*—Residue from leached-out siliceous limestone.

For opal as a precious stone see p. 571.

## THE FELDSPARS.

The feldspars here described are:

|             |  |            |
|-------------|--|------------|
| Orthoclase  | $\text{KAlSi}_3\text{O}_8$   | Monoclinic |
| Microcline  | $\text{KAlSi}_3\text{O}_8$   | Triclinic  |
| Plagioclase | $m(\text{NaAlSi}_3\text{O}_8) + n(\text{CaAl}_2\text{Si}_2\text{O}_8)$ | Triclinic  |

*Albite*, *oligoclase*, *andesite*, *labradorite*, *bytownite* and *anorthite* are included under plagioclase and the barium feldspars *hyalophane* and *celsian* are briefly mentioned after orthoclase.

This group of silicates constituting nearly sixty per cent. of the crust of the earth is believed to be composed of three fundamental substances,  $\text{KAlSi}_3\text{O}_8$ ,  $\text{NaAlSi}_3\text{O}_8$  and  $\text{CaAl}_2\text{Si}_2\text{O}_8$ . The isomorphous mixtures of these are given different names, but they all have many points of close resemblance, such as crystal angles, habit, modes of twinning, cleavage angles, hardness and specific gravity.

### FORMATION AND OCCURRENCE OF FELDSPARS.

Their occurrences may be summarized as follows:

#### Crystallization from Magma.

*Orthoclase*.—Opaque or nearly in granite, syenite, porphyry and more glassy in trachyte, phonolite, rhyolite, etc.

*Microcline*.—In granites.

*Albite*.—Not prominent as a primary mineral. On chemical grounds considered to be present in granites, groundmass of porphyry, etc., and acid eruptives.

*Oligoclase* and *andesite*.—More common in granites than albite. Very frequent also in syenite, diorite, trachyte, andesite, diabase, etc.; and particularly accompanies orthoclase.

*Labradorite* and *bytownite* are especially in gabbros and norites but also in other basic rocks, diorite, diabase, basalt, andesite, etc.

*Anorthite*.—In gabbro and norite, basalt, etc., especially if carrying chrysolite. Much rarer than labradorite.

#### Pegmatites.

The feldspars, particularly orthoclase, microcline, albite and oligoclase, are the principal minerals of the pegmatites.

#### Contacts.

Anorthite occurs as a contact mineral with limestone at Monzoni, Tyrol.

### Veins.

*Orthoclase*.—The variety *valencianite* (essentially *adularia*), occurs in many of the younger ore veins evidently deposited from the ascending currents and often replacing former gangue minerals.\* Examples are Tonopah, Nevada, Gold Road, Arizona, Cripple Creek, Colorado; Valencia, Guanajuato.

### Sediments.

The arkose sandstones of Portland, Conn., are high in feldspars and they are abundant as fragments and in shales and slates. The potash feldspars predominate.

### In Metamorphic Rocks.

The plagioclases are less abundant than *orthoclase* and *microcline*.

The potash feldspar is usually *microcline*.† *Adularia*, however, occurs in clefts in the crystalline schists as in the Alps.

*Albite* is common in gneiss and the schists (chlorite schists of Alps) and in metamorphosed eruptives.

*Labradorite* is found in many amphibolites.

### THE OPTICAL DETERMINATION OF FELDSPARS.

If the mineral is a feldspar sections in balsam will show frequent crystal outlines, low relief like that of quartz, gray to middle first order colors, frequent cleavage cracks and twinning, biaxial interference figures and very often cloudiness from weathering. Crushed fragments will be lath-like.

If *orthoclase* twinning will be common and sections showing it will be divided into two parts, Fig. 478, which extinguish for different positions between crossed nicols (*Carlsbad* law) or the division will be diagonal with the two parts extinguishing at the same

FIG. 478.



Sanidine, Carlsbad twin. (Cohen.)

\* Lindgren, *Mineral Deposits*, 434 to 438.

† Iddings, "Rock Minerals," 237.

time but with the  $X$  and  $Z$  directions crossed (*Baveno law*); the material will rarely be clear and pellucid.

If *microcline* most sections will show between crossed nicols the plaid or grating structure of dark and light bands due to two systems of twinning, as shown in Fig. 479.

FIG. 479.



Microcline grating structure. (Finlay.)

If *plagioclase* there will usually show between crossed nicols parallel dark and light bands due to multiple twinning, with the lamellæ parallel to  $(010)$  the brachy pinacoid (*Albite law*), which may be broad, Fig. 480, or narrow, Fig. 481, or both, or may pinch out. Sometimes a second series crosses these at different angles in different varieties (*Pericline law*).

**The More Exact Optical Determination in Sections of Known Orientation by Extinction Angles.**

On account of the two easy cleavages  $(001)$  and  $(010)$  flakes of known orientation are easily obtained and crushed fragments also tend to furnish these though in orthoclase plates parallel  $(001)$  predominate while in plagioclase plates parallel  $(010)$  are more common because of the lamellar development parallel to it.

These cleavage sections are much used, the "Guide" or reference line in each being the trace of the other cleavage. The extinction angles may be positive or negative, the rule being that with the sections in the positions of Figs. 482 and 483, with the cleavage

FIG. 480.



Plagioclase, showing broad lamellæ, in gabbro. (Cohen.)

FIG. 481.



Plagioclase, showing narrow lamellæ, in diabase. (Cohen.)

cracks parallel to a cross hair, clockwise rotations are + (positive) and counter clockwise are - (negative).

FIG. 482.

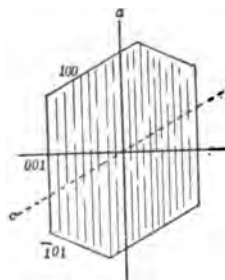
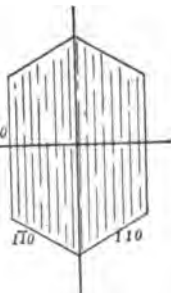


FIG. 483.



Feldspars.

Section (010).

Section (001).

These angles together with other constants are as follows:

| Species          | Indices. |          | Birefringence. | Extinction Angles. |          | Michel Levy. |
|------------------|----------|----------|----------------|--------------------|----------|--------------|
|                  | $\gamma$ | $\alpha$ |                | on (101)           | on (010) |              |
| Orthoclase.....  | 1.526    | 1.519    | 0.007          | 0°                 | + 5°     |              |
| Microcline.....  | 1.529    | 1.522    | 0.007          | + 15½°             | + 5½°    | 18°          |
| Albite.....      | 1.540    | 1.532    | 0.008          | + 4°               | + 19½°   | 16°          |
| Oligoclase.....  | 1.545    | 1.537    | 0.008          | + 2°               | + 8°     | 5°           |
| Andesite.....    | 1.557    | 1.549    | 0.008          | - 2½°              | - 8°     | 16°          |
| Labradorite..... | 1.563    | 1.555    | 0.008          | - 5°               | - 18°    | 27°          |
| Anorthite.....   | 1.588    | 1.575    | 0.013          | - 37°              | - 36°    | 53°          |



*Extinctions on Sections Perpendicular to (010).* *Michel Lévy Method.*—In rock sections (010) and (001) may be difficult to find but any section perpendicular to a twin plane will, when the twin is parallel to one of the nicols, be *equally illuminated* and the angles of extinction with this line will be equal. But there are many such sections giving different extinction angles and only the *maximum* extinction angles are characteristic. Hence numerous sections must be tried and only the larger angles considered. The maximum extinction angles are tabulated above. Fouqué determined the orientation of sections by convergent light tests in sections perpendicular the acute or obtuse bisectrix.

#### ORTHOCLASE.—Feldspar, Potash Feldspar.

COMPOSITION.— $\text{KAlSi}_3\text{O}_8$ , with some replacement by Na.

GENERAL DESCRIPTION.—Cleavable masses, showing angle of  $90^\circ$ ; and monoclinic crystals, of flesh-red, yellow or white color. Also compact, non-cleavable masses, resembling jasper or flint. Sometimes colorless grains or crystals.

CRYSTALLIZATION.—Monoclinic. Axes  $\beta = 63^\circ 57'$ ;  $a : b : c = 0.659 : 1 : 0.555$ .  $\beta = 63^\circ 57'$ . Most frequent forms: unit prism  $m$ , pinacoids  $b$  and  $c$  and positive orthodomes  $o = (a : \infty \bar{b} : c)$ ;  $\{101\}$ ; and  $y = (a : \infty \bar{b} : 2c)$ ;  $\{201\}$ . Supplement angles are:  $mm = 61^\circ 13'$ ;  $cm = 67^\circ 47'$ ;  $co = 50^\circ 17'$ ;  $cy = 80^\circ 18'$ .

FIG. 484.

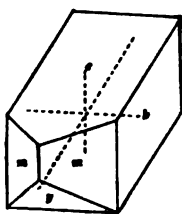


FIG. 485.

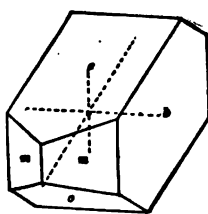


FIG. 486.

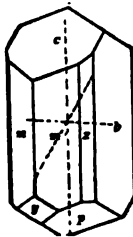


FIG. 487.



Twin forms of Carlsbad type, Fig. 488, twin plane the orthopinacoid, are very common; the Baveno type, Fig. 489, twin plane a clinodome, and Mannebacher type, twin plane the base  $c$ , Fig. 490, are less common.

FIG. 488.

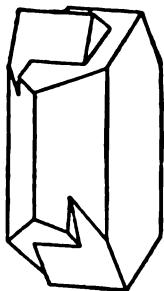


FIG. 489.

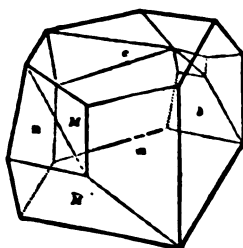
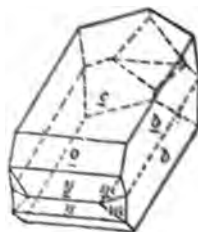


FIG. 490.



**Physical Characters.** H., 6 to 6.5. Sp. gr., 2.44 to 2.62.

LUSTRE, vitreous or pearly.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, flesh-red, yellowish, white, colorless, gray, green.

CLEAVAGE, parallel to  $c$  and  $b$ , hence at right angles.

BEFORE BLOWPIPE, ETC. — Fuses in thin splinters to a semi-transparent glass and colors the flame violet. Insoluble in acids.

#### VARIETIES.

*Ordinary.* — Simple or twinned crystals, sometimes of great size, of nearly opaque pale red, pale yellow, white or green color. More frequently imperfectly formed crystals and cleavable masses, in the granitic rocks.

*Adularia.* — Colorless to white, transparent, often opalescent. Usually in crystals.

*Sanidine and Rhyacolite.* — Glassy, white or colorless crystals in lava, trachyte, etc.

*Loxoclase.* — Grayish-white or yellowish crystals, which have a tendency to cleave parallel to the ortho pinacoid.

*Felsite.* — Jaspery or flint-like masses of red or brown color.

**SIMILAR SPECIES.** — Differs from the other feldspars in the cleavage at  $90^\circ$ , the greater difficulty of fusion, the absence of striations. The very common red or brownish color of orthoclase does not occur in plagioclase.

**REMARKS.**—The occurrence and uses are described on p. 488, and 481. It changes to kaolin quartz, opal, epidote and sericite, by the removal of bases through the action of acid waters. Orthoclase is quarried at South Glastonbury and Middletown, Conn.; Edgecomb and Brunswick, Me.; Chester, Mass.; Brandywine Summit, Pa.; Tarrytown and Fort Ann, N. Y., and the Spruce Pine district, N. C.

**HYALOPHANE.**  $(K, Ba)Al_2(SiO_3)_4$  and **CELSIAN.**  $BaAl_2Si_2O_8$ , are barium

feldspars, stated by Iddings to be "monoclinic in all discernible physical properties." The former resembles adularia and occurs in dolomite in Binnenthal, Switzerland, and Jakobsberg, Sweden. The latter is massive cleavable from Jakobsberg, Sweden.

#### MICROCLINE.

COMPOSITION.— $\text{KAlSi}_3\text{O}_8$ .

GENERAL DESCRIPTION.—Like orthoclase. There is no practicable macroscopic distinction between orthoclase and microcline and it is very probable that they are identical.

One theory is that the individuals are triclinic and submicroscopic, but that in orthoclase they alternate in twin position, remaining invisible and giving an "apparent monoclinic" structure, whereas in microcline a number of successive individuals are parallel followed by a number in twin position, thereby becoming visible as twin lamellæ, but grading into submicroscopic and apparently monoclinic portions.

REMARKS.—The distinctions are optical (see p. 491 and Fig. 479).

#### PLAGIOCLASE.—Albite, Anorthite, and Isomorphous Mixtures.

The name "*plagioclase*" was originally given to minerals closely resembling common feldspar in cleavage, crystal form, mode of occurrence, hardness, specific gravity and other physical characters, but with the angle between the two cleavages about  $86^\circ$  instead of  $90^\circ$ . The very great variations in composition led to the establishment of several species, in which, however, the variations in composition were still great, and finally to a theory, now generally accepted, which may be expressed as follows: *The plagioclases consist of isomorphous mixtures of two (or three) triclinic compounds,  $\text{NaAlSi}_3\text{O}_8$  and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (and  $\text{KAlSi}_3\text{O}_8$ ). Some specimens approach the end members, and are then called respectively albite, anorthite (and microcline), but, in general, distinct species cannot be said to exist.*

In accordance with this, the more prominent species names are here given as varieties of the group name PLAGIOCLASE.

COMPOSITION. —  $m(\text{NaAlSi}_3\text{O}_8) + n(\text{CaAl}_2\text{Si}_2\text{O}_8)$ , with some replacement by  $\text{KAlSi}_3\text{O}_8$ .

GENERAL DESCRIPTION. — Granular masses or small triclinic crystals, or coarser masses. Each grain or crystal cleaves easily in two directions, which make an angle of about  $86^\circ$  with each other, and shows on one or both surfaces by reflected light the parallel "twin striations." Some varieties show marked play of colors, others the moonstone effect. Usually light colored, and most frequently colorless, white or faintly tinged, sometimes (labradorite) dark gray. Just about the hardness of a good knife.

CRYSTALLIZATION. — Triclinic, usually in crystals resembling that shown in Fig. 491, with supplement angles  $mM$  approximately  $60^\circ$ , and frequently twinned either by the albite law, twin plane  $b$ , Fig. 492, which, if repeated, results in striations on  $c$ ; or by the pericline law, twin axis the macro axis, Fig. 493, producing striations on  $b$ . 2/

Albite and anorthite are frequently crystallized, the other varieties less frequently.

FIG. 491.

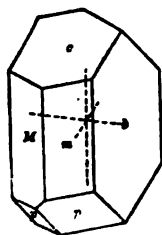


FIG. 492.

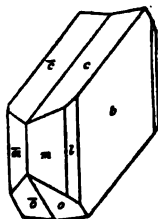
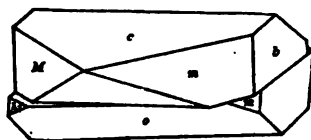


FIG. 493.



COMPOSITION AND SPECIFIC GRAVITY OF TYPES.—Denoting  $\text{NaAlSi}_3\text{O}_8$  by Ab and  $\text{CaAl}_2\text{Si}_2\text{O}_8$  by An the names most used are as follows:

|             |  |
|-------------|--|
| ALBITE      | $\text{Ab}_1\text{An}_0$ to $\text{Ab}_6\text{An}_1$ |
| OLIGOCLEASE | $\text{Ab}_6\text{An}_1$ to $\text{Ab}_3\text{An}_1$ |
| ANDESINE    | $\text{Ab}_3\text{An}_1$ to $\text{Ab}_1\text{An}_1$ |
| LABRADORITE | $\text{Ab}_1\text{An}_1$ to $\text{Ab}_1\text{An}_3$ |
| BYTOWNITE   | $\text{Ab}_1\text{An}_3$ to $\text{Ab}_1\text{An}_6$ |
| ANORTHITE   | $\text{Ab}_1\text{An}_6$ to $\text{Ab}_6\text{An}_1$ |

The percentage composition and specific gravities of types are:

|                                | Sp. Gr.* | $\text{SiO}_2$ | $\text{Al}_2\text{O}_3$ | $\text{Na}_2\text{O}$ | $\text{CaO}$ |
|--------------------------------|----------|----------------|-------------------------|-----------------------|--------------|
| $\text{Ab}_1\text{An}_0$ ..... | 2.605    | 68.7           | 19.5                    | 11.8                  | 0            |
| $\text{Ab}_6\text{An}_1$ ..... |          | 64.9           | 22.1                    | 10.0                  | 3            |
| $\text{Ab}_3\text{An}_1$ ..... | 2.649    | 62.0           | 24.0                    | 8.7                   | 5.3          |
| $\text{Ab}_1\text{An}_1$ ..... | 2.679    | 55.6           | 28.3                    | 5.7                   | 10.4         |
| $\text{Ab}_1\text{An}_3$ ..... |          | 49.3           | 32.6                    | 2.8                   | 15.3         |
| $\text{Ab}_1\text{An}_6$ ..... |          | 46.6           | 34.1                    | 1.6                   | 17.4         |
| $\text{Ab}_6\text{An}_1$ ..... | 2.765    | 43.2           | 36.7                    | 0                     | 20.1         |

\* On pure artificial feldspars also  $\text{Ab}_2\text{An}_1$  2.660,  $\text{Ab}_1\text{An}_2$  2.710,  $\text{Ab}_1\text{An}_5$  2.733. Natural material is impure and ranges 2.5 to 2.8.

c' **Physical Characters.** H., 5 to 7- Sp. gr.. 2.5-2.8 in minerals.

LUSTRE, vitreous or pearly.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, varies.

CLEAVAGES, at 86° approx.

Before Blowpipe. Fusion and solubility variable, depending on chemical composition.

Distinguishing the Varieties.

7. Something can be judged by the occurrence, p. 488. The end members, albite and anorthite, are less common than the others and the albite and oligoclase or andesine are to be expected in the more acid igneous rocks such as the granites, while the labradorite, bytownite and anorthite favor the dark-colored basic rocks. In the schists and metamorphic rocks generally albite is common.

The optical distinctions as outlined on p. 490 are conclusive if the orientation is known.

A few simple macroscopic indications are as follows:

*Albite*.—Usually pure white, granular or with curved cleavage surfaces, or in crystals (Figs. 491 to 493) in cavities. Often encloses the rarer minerals, tourmaline, beryl, chrysoberyl, topaz, etc. Not easily altered.

American localities are Branchville, Conn.; Paris, Maine; Chesterfield, Mass.; Amelia Co., Virginia; Pikes Peak, Colorado.

*Oligoclase* often accompanies orthoclase as grayish white, translucent masses, with somewhat greasy lustre and marked twin striations. Occurs also as reddish cleavable masses, *sunstone*, and rarely as crystals.

American localities are Fine and McComb, New York; Mineral Hill, Penn.; Bakersville, N. C.

*Andesine* is similar to oligoclase.

Observed in the granular and volcanic rocks of the Andes. Also common in the Rocky Mts., Sandford, Maine, etc.

*Labradorite* is usually in dark gray cleavable masses often associated with hypersthene. Commonly iridescent, showing beautiful changing colors, blue, green and red, from inclusions of diallage, ilmenite or goethite. Striated like oligoclase. Is notably absent in localities containing orthoclase and quartz.

Found abundantly in the Adirondacks, N. Y., in the Wichita Mountains, Ark., in Quebec and in Labrador.

*Bytownite*, originally a greenish white feldspar from Bytown, Canada, is now simply a name for plagioclase between labradorite and anorthite.

*Anorthite*.—Comparatively rare as a pure mineral.

Best known in the small glassy crystals of Vesuvius and the white crystals of Miyake, Japan, often covered with a black crust, the massive granular *indianite* from India, and the contact mineral of Monzoni, Tyrol.

### THE FELDSPATHOIDS.

The minerals described are:

|                       |                              |            |
|-----------------------|------------------------------|------------|
| <i>Leucite</i>        | $K_2Al(SiO_3)_2$             | Isometric  |
| <i>Melilite</i>       | $Ca_{12}Al_4(SiO_4)_2$       | Tetragonal |
| <i>Nephelite</i>      | $7NaAlSiO_4 + NaAl(SiO_3)_2$ | Hexagonal  |
| <i>Sodalite Group</i> |                              | Isometric  |

The analcite, p. 531, of certain plutonic rocks near Butte, Montana, and Pikes Peak, Colorado, and the dike at Heron Bay, L. S., also belongs here.

#### FORMATION AND OCCURRENCE OF FELDSPATHOIDS.

Feldspathoids are\* "Silicates of alumina and an alkali or alkaline earth that are practically equivalent to feldspars in their relation to rocks."

They form from magmas unusually rich in sodium or potassium and are limited to igneous rocks or rarely to schists resulting from metamorphosis of igneous rocks.

Two divisions may be made.

#### In Volcanic Rocks.

*Leucite*.—Almost entirely confined to younger eruptive rocks, phonolite, tephrite and other leucite rocks and their tuffs.

*Melilite*.—Restricted to younger basic eruptives, such as augite bearing basalts.

*Nephelite*.—In glassy crystals in volcanic ejecta, phonolite-tephrite, etc.

*Noselite and Hauynite*.—Almost limited to microscopic material in phonolite, etc., and always associated with nephelite or leucite,

*Sodalite*.—In microscopic crystals, trachytes, phonolites and lava.

---

\* Kemp, "Handbook of Rocks," p. 186.

**In Plutonic Rocks.**

*Leucite* rare but often represented by pseudomorphs.

*Nephelite* as massive and coarsely crystalline elæolite in elæolite-syenite.

*Sodalite* common in elæolite-syenite.

**OPTICAL DETERMINATION OF FELDSPATHOIDS.**

|                          |           | $\gamma$    | $\alpha$ | $\gamma - \alpha$ |
|--------------------------|-----------|-------------|----------|-------------------|
| Leucite.....             | Biaxial   | + 1.5809    | 1.5808   | 0.001             |
| Melilite.....            | Uniaxial  | $\pm$ 1.631 | 1.629    | 0.002             |
| Nephelite.....           | Uniaxial  | - 1.542     | 1.538    | 0.004             |
| Sodalite.....            | Isotropic |             | 1.483    |                   |
| Hauynite }<br>Noselite } | Isotropic |             | 1.496    |                   |

**In Thin Sections.**

*Leucite*.—Nearly round cross sections. Isotropic in small crystals but showing intersecting twin lamellæ and zonal inclusions in larger crystals. No relief, smooth surface. Low bluish-gray interference colors best proved with gypsum red test plate.

*Melilite*.—Lath-shaped sections or irregular often with markings parallel the length. Marked relief. Very low interference colors or abnormal, p. 138.

*Nephelite*.—Rectangular or hexagonal sections in volcanic rock shapeless in plutonic. No relief, smooth surface, low first order interference colors. Basal sections give broad cross, no rings. Other sections extinguish parallel cleavages.

*Hauynite*, *Noselite*, *Sodalite*.—Dodecahedral crystals or shapeless. Surface rather rough. Gas and glass inclusions especially near border. Dark between crossed nicols or abnormal. Distinctions by microchemical tests.

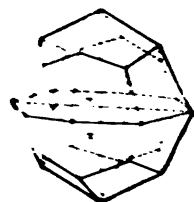
**LEUCITE.**

COMPOSITION.— $\text{KAlSi}_3\text{O}_8$

GENERAL DESCRIPTION.—Gray, translucent to white and opaque, disseminated grains and trapezohedral crystals in volcanic rock.

CRYSTALLIZATION.—Isometric externally, but with polarized light showing double refraction at all temperatures below 500° C.

FIG. 494.



**Physical Characters.** H., 5.5 to 6. Sp. gr., 2.45 to 2.50.

LUSTRE, vitreous to greasy, TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white or gray, or with yellowish or red tint.

**BEFORE BLOWPIPE, ETC.** Infusible. With cobalt solution, becomes blue. Soluble in hydrochloric acid, leaving a fine powder of silica.

**REMARKS.**—It is not common in America, but is found in the Leucite Hills, Wyoming, and also in the northwestern part of the same state, and in Montana. It is represented by pseudomorphs at Magnet Cove, Arkansas. Very common in the Vesuvian lavas and in other parts of Italy.

**MELLILITE.**— $\text{Ca}_{12}\text{Al}_4(\text{SiO}_4)_2$  with Na, Mg and Fe replacing Ca and Al, occurs in short prisms and in tabular tetragonal crystals. Color, honey-yellow to brown. H., 5. Sp. gr., 2.9. Fuses quite easily to a yellowish or green glassy globule. Gelatinizes with hydrochloric acid.

It is found in the Vesuvian lavas, certain basalts of Württemberg and the Sandwich Islands and elsewhere.

#### **NEPHELITE.—Elæolite.**

**COMPOSITION.**— $7\text{NaAlSiO}_4 + \text{NaAl}(\text{SiO}_3)_2$ . With partial replacement of Na by K or Ca.

**GENERAL DESCRIPTION.**—Small, glassy, white or colorless grains or hexagonal prisms with nearly flat ends, in lavas and eruptive rocks, or translucent reddish-brown or greenish masses and coarse crystals, with peculiar greasy lustre.

**Physical Characters.** H., 5.5 to 6. Sp. gr., 2.55 to 2.65.

LUSTRE, vitreous or greasy. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, white, colorless, reddish, brownish, greenish or gray.

CLEAVAGE, prismatic and basal.

**BEFORE BLOWPIPE, ETC.**—Fuses to a colorless glass. When heated with cobalt solution, becomes blue. Soluble in hydrochloric acid, with residue of gelatinous silica.

**VARIETIES.**—The usually massive varieties, with greasy lustre, are called elæolite.

**REMARKS.**—Southern Norway; Greenland; Miask, Urals; Austin, Texas; Litchfield, Me.; Salem, Mass.; the Ozark Mountains, Arkansas; Cripple Creek, Col., are important localities of elæolite. Nephelite is abundant in the lavas of Vesuvius, and in basalts near Heidelberg, Germany, and Aussig, Bohemia.



## THE SODALITE GROUP.

A group of silicates containing the unusual radicals Cl, SO<sub>3</sub> and S. The formulae as written and the isometric crystallization suggest a relationship to garnet.

**SODALITE.**—Na<sub>4</sub>(AlCl)Al<sub>3</sub>(SiO<sub>4</sub>)<sub>3</sub> is found in bright blue to gray masses, embedded grains, concentric nodules resembling chalcedony and rarely dodecahedral crystals sometimes of a pale pink color. It occurs at Litchfield, Me., various localities in Montana, Quebec, and Ontario; also in Vesuvius lavas, at Kaiserstuhl, Baden; and Miask, Urals.

**HAÜYNITE.**—2(Na<sub>2</sub>Ca)Al<sub>2</sub>(SiO<sub>4</sub>)<sub>2</sub>(Na<sub>2</sub>Ca)SO<sub>4</sub> possibly, but very complex and with varying proportions of Na and Ca. Occurs as glassy blue to green imbedded grains, or rounded isometric crystals in igneous rock.

**NOSELITE.**—Na<sub>4</sub>(NaSO<sub>4</sub>Al)Al<sub>3</sub>(SiO<sub>4</sub>)<sub>3</sub> not distinguishable from haüynite except by microchemical tests.\*

*Haüynite* is from Mt. Dore, Puy de Dome; Vesuvian lavas, the Eifel and Crary Mt., Montana.

*Noselite* is from Lake Laach, Cape Verde Islands, etc.

## THE PYROXENE AND AMPHIBOLE GROUPS.

## THE PYROXENE GROUP.

|                     |                                      |              |
|---------------------|--------------------------------------|--------------|
| <i>Enstatite</i>    | (Mg.Fe)SiO <sub>3</sub>              | Orthorhombic |
| <i>Hypersthene</i>  | (Mg.Fe)SiO <sub>3</sub>              | Orthorhombic |
| <i>Pyroxene</i>     | RSiO <sub>3</sub>                    | Monoclinic   |
| <i>Acmite</i>       | NaFe(SiO <sub>3</sub> ) <sub>2</sub> | Monoclinic   |
| <i>Wollastonite</i> | CaSiO <sub>3</sub>                   | Monoclinic   |

Other described species belonging to this group are spodumene, rhodonite, and jadeite.

## THE AMPHIBOLE GROUP.

The minerals described are:

|                      |  |              |
|----------------------|--|--------------|
| <i>Anthophyllite</i> | (Mg.Fe)SiO <sub>3</sub>                                      | Orthorhombic |
| <i>Amphibole</i>     | RSiO <sub>3</sub>  | Monoclinic   |
| <i>Glaucophane</i>   | NaAl(SiO <sub>3</sub> ) <sub>2</sub> (Fe.Mg)SiO <sub>3</sub> | Monoclinic   |
| <i>Crocidolite</i>   | NaFe(SiO <sub>3</sub> ) <sub>2</sub> FeSiO <sub>3</sub>      |              |

The compositions of the two groups are related, but while the amphiboles are largely formed from the pyroxenes† corresponding members are lower in calcium and higher in magnesium. There

\* For instance gypsum crystals obtained by evaporating the hydrochloric acid solution prove haüynite.

† When the amphibole retains the outward form of the pyroxene it is called *uralite*. The change usually commences on the surface and the *uralite* does not form a single compact crystal, but consists of numerous slender columns parallel to one another. These little columns or fibers have their *c* and *b* axes parallel to the positions of these axes in the parent mineral.

are also close relations in crystalline form, as shown by the following comparison of constants:

Pyroxene  $a : b : c = 1.0921 : 1 : 0.5893$   $\beta = 74^\circ 10'$

Amphibole  $a : \frac{1}{2}b : c = 1.1022 : 1 : 0.5875$   $\beta = 73^\circ 58'$

The "habit" and cleavage are however always different.

#### FORMATION AND OCCURRENCE OF PYROXENES AND AMPHIBOLES.

The occurrences may be classed as

##### **Separations from Magma in Plutonic Rocks.**

###### **PYROXENES.**

*Diopside*, and some *augites* in granites, syenites and diorites.

*Enstatite*, *hypersthene*, *diopside*, *diallage* and darker *augites*; in more basic rocks, gabbros, norites, pyroxenites, peridotites, etc.

*Acmite* in nephelin syenites, granites, etc.

###### **AMPHIBOLES.**

*Common hornblende* in granite, syenite, diorite, gabbro.

*Basaltic hornblende* in gabbro.

##### **Separations from Magma in Volcanic Rocks.**

###### **PYROXENES.**

*Augite* as important constituent of many volcanic rocks, especially basalt, melaphyre, diabase, andesite, porphyries, and ash and tuff of volcanoes.

*Enstatite* and *hypersthene* as accessories in small crystals.

*Acmite* in leucite and nephelite rocks.

*Diopside* and *sahlite* rare. No *diallage*.

###### **AMPHIBOLES.**

*Basaltic hornblende* chiefly in basalts, andesites, and volcanic tuffs.

##### **Secondary Crystallizations in Igneous Rocks.**

The amphibole *actinolite* is common, sometimes formed from pyroxene, sometimes from hornblende. Secondary pyroxene is rare.

##### **Contacts.**

The PYROXENES, *fassaite*, *wollastonite*, *diopside*, *sahlite* and sometimes *augite* and the AMPHIBOLES, *edenite*, and common *hornblende*.

**In Metamorphic Rocks.****PYROXENES.**

*Diopside* and *sahlite* in clefts in the schists or in granular limestone.

*Augite* less frequent.

*Enstatite* and *hypersthene* in metamorphosed igneous rocks, serpentine and some gneiss.

**AMPHIBOLES.**

*Tremolite* always metamorphic, especially in granular limestone and dolomite in regions of crystalline schists.

*Actinolite* is more widespread, not only as a secondary mineral in igneous rocks resulting from the alteration of pyroxene but forming *actinolite* schists with chlorite and epidote or magnetite and as crystallizations in talc.

*Hornblende* is common, sometimes forming hornblende schist and hornblende gneiss.

*Anthophyllite* and *glaucothane* occur in schists, the former often with hornblende or actinolite, the latter sometimes forming independent *glaucothane* schists.

**OPTICAL DETERMINATION OF PYROXENES AND AMPHIBOLES.**

The characters of use in distinction are:

|                    | Refractive Indices. |          | Birefringence.    | Extinct.   | Pleochroism.                     |
|--------------------|---------------------|----------|-------------------|------------|----------------------------------|
|                    | $\gamma$            | $\alpha$ | $\gamma - \alpha$ | On oro.    |                                  |
| <b>PYROXENES:</b>  |                     |          |                   |            |                                  |
| Enstatite.....     | 1.669               | 1.665    | 0.009             | 0°         | Weak                             |
| Hypersthene.....   | 1.705               | 1.692    | 0.013             | 0°         | Strong, red to green             |
|                    | 1.702               | 1.680    | 0.022             |            |                                  |
| Diopside.....      | to                  | to       | to                | 38° to 45° | None                             |
|                    | 1.727               | 1.706    | 0.021             |            |                                  |
| Augite.....        | 1.722               | 1.697    | 0.025             | 38° to 54° | Not intense                      |
| Acmite.....        | 1.813               | 1.763    | 0.050             | 2° to 5°   | Strong, yellow to green or brown |
| Wollastonite.....  | 1.635               | 1.621    | 0.014             | 35°        | None                             |
| <b>AMPHIBOLES:</b> |                     |          |                   |            |                                  |
| Anthophyllite..... | 1.657               | 1.633    | 0.024             | 0°         | Sometimes                        |
| Tremolite.....     | 1.636               | 1.609    | 0.027             | 16°        | None                             |
| Actinolite.....    | 1.636               | 1.611    | 0.025             | 15°        | Weak                             |
| Hornblende*        | 1.653               | 1.629    | 0.024             | 15° to 25° | Strong yellow to green           |
| Glaucothane.....   | 1.639               | 1.621    | 0.018             | 4° to 6°   | Strong blue to yellow            |

The indices indicate marked relief and rough surfaces in balsam. Interference colors in thin sections (due to  $\gamma - \alpha$ ) will be rather low in enstatite, hypersthene

and wollastonite. The other pyroxenes will show very bright colors, more so than the amphiboles because of the strong absorption of the latter in direction of cleavage lines of longitudinal sections.

In convergent light. All are biaxial with axial plane (010).

**Pyroxenes:**

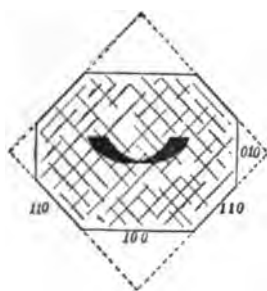
|                   | Axial angle. | Sign.  | Acute bisectrix.                             |
|-------------------|--------------|--------|--|
| Enstatite.....    | Large        | +      | $\parallel c$                                |
| Hypersthene.....  | Large        | -      | $\parallel d$                                |
| Pyroxene.....     | Large        | +      | $-36^{\circ}$ to $54^{\circ}$ to $c$ (front) |
| Acmite.....       | Small        | -      | nearly $\parallel c$                         |
| Wollastonite..... | Large        | - or + | $+32^{\circ}$ to $c$ (back)                  |

**Amphiboles:**

|                    |        |   |  |
|--------------------|--------|---|--|
| Anthophyllite..... | Large  | + | $\parallel c$                              |
| Amphibole.....     | Large  | - | $-70^{\circ}$ to $90^{\circ}$ to $c$ front |
| Glaucophane.....   | Medium | - | $-84^{\circ}$ to $86^{\circ}$ to $c$ front |

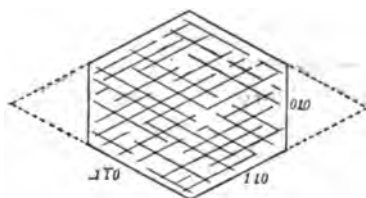
Basal sections show characteristically different outlines and cleavage lines in pyroxene, Fig. 495, and in amphibole, Fig. 496. They yield symmetrical interference figures, Fig. 266, with *enstatite*, *hypersthene* and *anthophyllite*, and may show the emergence of an optic axis, Fig. 269, with the other pyroxenes and glaucophane.

FIG. 495.



Pyroxene.

FIG. 496.



Amphibole.

The section (010) yields the most characteristic tests, giving maximum birefringence (interference colors) pleochroism and extinction angles. It is parallel to the axial plane therefore may give the interference figure of Fig. 267.

In finding (010) in a rock section a partial guide is the one system of parallel cleavage lines (so also on 100) and these maximum interference colors and pleochroic differences.

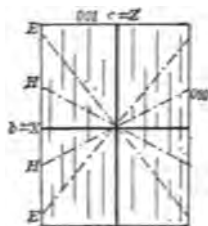
The extinction angle results when the longitudinal section,

\* In basaltic hornblende the indices are higher and birefringence so high that no bright colors result and the extinction varies from  $0^{\circ}$  to  $+10^{\circ}$ .

Figs. 497, 498, 499, is revolved from the cleavage lines as a reference to the *nearest* extinction.

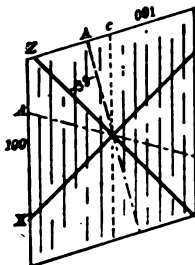
This direction will be X in acmite, and wollastonite and Z in the others and this may be proved by test, p. 134. for faster and slower ray (elongation).

FIG. 497.



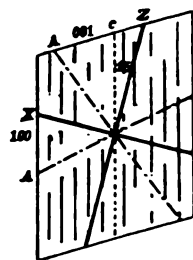
Enstatite-Hypersthene.

FIG. 498.



Pyroxene (Diopside).

FIG. 499.



Amphibole (Tremolite).

## THE ORTHORHOMBIC PYROXENES.

### Enstatite and Hypersthene.

Natural iron free  $\text{MgSiO}_3$  is not known.

**COMPOSITION.**— $(\text{Mg.Fe})\text{SiO}_3$ . Although these two substances have the same general formula and nearly identical axial ratios, the increase in iron contents not only affects such characters as color fusibility, and specific gravity but the position of the optic axes so that Des Cloizeaux made the distinction,\* on the basis of the fact that with about 10 per cent.  $\text{FeO}$  the optic axial angle was  $90^\circ$ , between

*Enstatite* with  $\text{FeO} < 10$  per cent. and optically +.

*Hypersthene* with  $\text{FeO} > 10$  per cent. and optically −.

### ENSTATITE.—Bronzite.

**COMPOSITION.**— $(\text{Mg.Fe})\text{SiO}_3$ .

**GENERAL DESCRIPTION.**—Brown to gray or green, lamellar or fibrous masses, with sometimes a peculiar metalloidal lustre (bronzite). Rarely in columnar orthorhombic crystals.

**PHYSICAL CHARACTERS.**—Translucent to opaque. Lustre, pearly, silky or metalloidal. Color, brown, green, gray, yellow. Streak, white. H., 5.5. Sp. gr., 3.1 to 3.3. Brittle.

**BEFORE BLOWPIPE, ETC.**—Fusible on the edges. Almost insoluble in acids. With cobalt solution is turned pink.

\* As Dana states it, "The essential difference between them, according to Des Cloizeaux, lies in the axial dispersion which is *uniformly*  $\rho < v$  for enstatite, and  $\rho > v$  for hypersthene."

**REMARKS.**—Occurrences as stated on p. 501; also found in meteorites. The largest crystals (pseudomorphs) are from the apatite-iron deposits of Bamle, Norway. The fibrous talc of Edwards, N. Y., is altered enstatite. Other localities are Kupferberg, Bavaria, and Baste, Harz.

#### HYPERSTHENE.

**COMPOSITION.**— $(\text{Mg.Fe})\text{SiO}_3$ , with more iron than enstatite

**GENERAL DESCRIPTION.**—Dark-green to black, foliated masses or rare orthorhombic crystals, which grade into enstatite. Frequently shows a peculiar iridescence, due to minute interspersed crystals.

**PHYSICAL CHARACTERS.**—Translucent to opaque. Lustre, pearly or metalloidal. Color, dark-green to black. Streak, gray. H., 5 to 6 Sp. gr., 3.4 to 3.5. Brittle

**BEFORE BLOWPIPE, ETC.**—Fuses on coal to a black, magnetic mass. Partially soluble in hydrochloric acid.

**REMARKS.**—It occurs at St. Paul, Labrador, and the Saranac Region, N. Y.; with labradorite; Bodenmais, Bavaria, in the intrusive pyrite deposit; Aranyer Berg, Hungary; Mt. Dore, Auvergne; etc.

**BASTITE.**—An alteration product of enstatite near serpentine in composition. It is usually foliated and of a yellowish or greenish color and has a peculiar bronze-like lustre on the cleavage surface. H., 3.5-4. Sp. gr., 2.5-2.7.

#### PYROXENE. — Augite.

**COMPOSITION.**— $\text{RSiO}_3$ . R = Ca, Mg, Mn, Fe, Al, chiefly.

**GENERAL DESCRIPTION.**—Monoclinic crystals. Usually short and thick, with square or nearly square cross-section, or octagonal and with well-developed terminal planes. Granular, foliated and columnar masses and *rarely* fibrous. Color, white, various shades of green, rarely bright green, and black.

**CRYSTALLIZATION.**—Monoclinic.  $\beta = 74^\circ 10'$ . Axes  $a : b : c = 1.092 : 1 : 0.589$ .

FIG. 500.

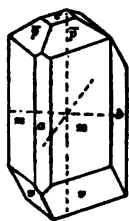
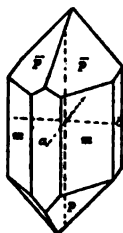
Diopside,  
Pitcairn, N. Y.

FIG. 501.



Rossie, N. Y.

FIG. 502.

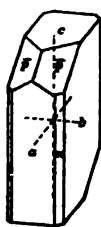
Diopside,  
De Kalb, N. Y.

FIG. 503.



Fassaite.

Common forms : unit prism  $m$ , the pinacoids  $a$ ,  $b$  and  $c$ , the negative and, more rarely, the positive unit pyramids  $\bar{p}$  and  $p$ , the

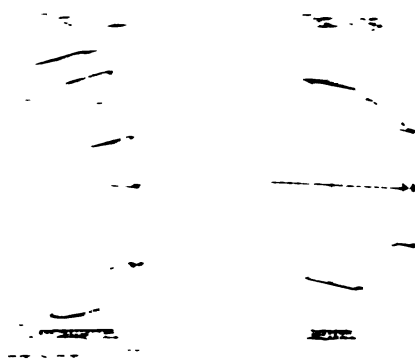
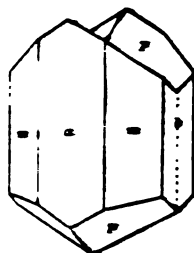


FIG 506



**Angite (wing)**

$$\overline{a} = a : \overline{b} : 2c ; \{22\overline{1}\}$$

$$\overline{\rho} = 43^{\circ} 29' ; \rho\rho =$$

$$\overline{\rho} = 33^{\circ} 49' ; \rho\rho =$$
[illegible]

Physical Dimensions      Fig. 3.2 to 3.6.

~~ENTRE DEUX~~      ~~PAQUE~~ to transparent

STRENGTH, ~~very~~ medium TENACITY, brittle.

התאריך: 19.01.2019

THE UNIVERSITY OF CHICAGO

Before Blowing. Etc.—Fragile. Usually fuses easily to dark glass, sometimes to magnetic powder. Not generally soluble in acids.

## VARIETIES

*Diagnosis.*—Larva 500  $\mu$ . Usually white or pale-green to nearly black.

*Chlorophytum* Swartz. — *Chlorophytum* Swartz. Chiefly shades of green and black.

*Asple*— $\text{CaMg}_2\text{SiO}_6$ , with  $\text{Mg}$ ,  $\text{Fe}$ ,  $\text{Al}$ ,  $\text{Fe}_2\text{SiO}_6$ . Dark-green to black.

In addition there are intermediate members of the isomorphous series such as  $\text{Fe}_2\text{SiO}_4$ ,  $\text{Ca-Fe SiO}_4$ , grayish-green. *Scheff-*

*ferite* containing up to 8 per cent. MnO, *jeffersonite* containing ZnO, and *diallage*, thin foliated pyroxene, green or brown in color.

**SIMILAR SPECIES.**—Differs from amphibole, as therein described.

#### ACMITE, *Agrite*.

**COMPOSITION.**— $\text{NaFe}(\text{SiO}_3)_2$ .

**GENERAL DESCRIPTION.**—Occurs in long, prismatic monoclinic crystals of dark green or dark brown color. Sometimes green on interior and brown on exterior of crystal. In acmite these are acutely terminated and in *agrite*, bluntly. Also found needle-like and fibrous. Streak, yellowish gray. H., 6–6.5. Sp. gr., 3.5.

**BEFORE BLOWPIPE, ETC.**—Fuses easily to a black, slightly magnetic globule, and colors the flame yellow. Only slightly affected by acids.

**REMARKS.**—Found at Magnet Cove, Ark.; Montreal, Canada; Langesund fiord, Norway; West Greenland, etc.

#### WOLLASTONITE.

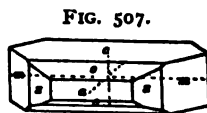
**COMPOSITION.**— $\text{CaSiO}_3$ ,  $\text{SiO}_2$  51.7, CaO 48.3.

**GENERAL DESCRIPTION.**—Cleavable to fibrous white or gray masses. Also in monoclinic crystals, near pyroxene in angle. Sometimes compact. Usually intermixed with calcite. H., 4.5 to 5. Sp. gr., 2.8 to 2.9.

**BEFORE BLOWPIPE, ETC.**—Fuses to a white glass, coloring the flame red. Soluble in hydrochloric acid, generally effervescing and always gelatinizing.

**SIMILAR SPECIES.**—Differs from pectolite and natrolite in red flame, difficulty of fusion, and absence of water. Tremolite does not gelatinize.

**REMARKS.**—Occurs chiefly in limestone contacts with pyroxene, calcite, garnet, etc. Abundant in Lewis and Warren Counties, New York, and at numerous localities in Hungary, Finland, Norway, etc.



Harrisville, N. Y.

#### ANTHOPHYLLITE.

**COMPOSITION.**— $(\text{Mg.Fe})\text{SiO}_3$ , corresponding to enstatite-hypersthene of the pyroxene group.

**GENERAL DESCRIPTION.**—Gray, brown or green lamellar, and fibrous masses often resembling asbestos. Rarely in orthorhombic crystals. H., 5.5 to 6. Sp. gr., 3 to 3.2.

**BEFORE BLOWPIPE, ETC.**—Fuses with difficulty to a black enamel which is attracted by the magnet. Insoluble in acids.

**REMARKS.**—Occurs at Franklin, Macon Co., N. C., with corundum, Kongsberg, Norway; Gèdres, France, etc. (*gedrite* is an aluminous variety).

#### AMPHIBOLE. — Hornblende.

**COMPOSITION.**— $\text{RSiO}_3$ , R being more than one of the elements, Ca, Mg, Fe, Al, Na and K.

**GENERAL DESCRIPTION.**—Monoclinic crystals either long with acute rhombic section or shorter with six-sided cross section.



Often with ends like flat rhombohedron. Also columnar, fibrous and granular masses, rarely lamellar, often radiated. Colors: white, or shades of green, brown or black.

FIG. 508.

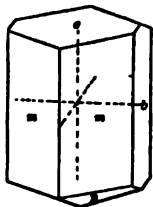
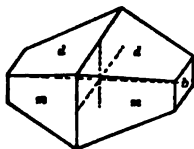
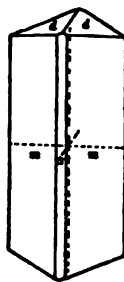


FIG. 509.



Russell, N. Y.

FIG. 510.



CRYSTALLIZATION. — Monoclinic. Axes  $a : b : c = 0.551 : 1 : 0.294$ ;  $\beta = 73^\circ 58'$ .

Common forms: unit prism  $m$ , pinacoids  $b$ ,  $c$  and sometimes  $a$ , unit clino-dome  $d$  and unit pyramid  $p$ . Supplement angles are:  $mm = 55^\circ 49'$ ;  $cm = 75^\circ 52'$ ;  $dd = 31^\circ 32'$ ;  $pp = 31^\circ 41'$ . Twinning as in pyroxene.

Optically +. Axial plane  $b$ . Strong double refraction. Often strongly pleochroic.

**Physical Characters.** H., 5 to 6. Sp. gr., 2.9 to 3.4.

LUSTRE, vitreous to silky. TRANSPARENT to opaque.

STREAK, white or greenish. TENACITY, brittle to tough.

COLOR, white, gray, green, black, brown, yellow and red.

CLEAVAGE, prismatic, angle of  $124^\circ 11'$ .

BEFORE BLOWPIPE, ETC.—Varies. Usually fuses easily to a colored glass, which may be magnetic. Not affected by acids.

#### VARIETIES:

*Tremolite*.— $\text{CaMg}_3(\text{SiO}_3)_4$ , white to gray in color. Crystals, long-bladed or short and stout. Fibrous masses, the fibres parallel, radiating or interlaced and compact masses. Originally from Tremola, Switzerland. Sp. gr., 2.9 to 3.1.

*Actinolite*.— $\text{Ca}(\text{Mg.Fe})_3(\text{SiO}_3)_4$ , bright green or grayish-green crystals and fibrous masses and compact (nephrite) as in tremolite. Sp. gr., 3 to 3.2.

*Hornblende*.\*— $\text{Ca}(\text{Mg.Fe})_3(\text{SiO}_3)_4$ , with aluminous compound.

\* See Bulletin 491, U. S. Geol. Survey, p. 367.

Sometimes written as  $(\text{Al.Fe})(\text{F.OH})\text{SiO}_3$ , sometimes as an ortho-silicate isomeric with garnet or mica.\* Crystals and blade-like masses varying from light green (*edenite*), dark green (*pargasite*) and black (common hornblende), but also mouse-colored and other shades.

Other varieties are *cummingtonite*  $(\text{Mg.Fe})\text{SiO}_3$ , *grünerite*  $(\text{FeSiO}_3)$ , *richterite*, containing 5 per cent. of  $\text{MnO}$ , etc.

*Nephrite* or *Jade* is compact and extremely tough, microscopically fibrous, may have composition of tremolite or actinolite.

*Asbestos* is in fine, easily separable fibres, white, gray, or greenish.

**SIMILAR SPECIES.**—Differs from tourmaline in cleavage, crystalline form and tendency to separate into fibres, from the fibrous zeolites in not gelatinizing with acids, from epidote in color, fusibility and cleavage. The differences between it and pyroxene are:

Amphibole, prism angle and cleavage  $124^\circ$ ; tough, often fibrous, rarely lamellar, often blade-like or pseudo-hexagonal crystals, usually simple. Pyroxene, prism and cleavage angle  $87^\circ$ ; brittle, rarely fibrous, often lamellar, crystals, square or octagonal and often complex.

**GLAUCOPHANE.**—A sodium amphibole,  $\text{NaAl}(\text{SiO}_3)_2(\text{Fe.Mg})\text{SiO}_3$ , blue in color and occurring in indistinct monoclinic prisms or in columnar and fibrous masses. Crystals show distinctly different colors when viewed by transmitted light through different faces. Cleavage prismatic. H., 6 to 6.5. Sp. gr., 3 to 3.1. It is widely distributed as glaucophane schists in the Coast Ranges of California; Syra, Greece; Zermatt, Switzerland, etc.

**CROCIDOLITE.** Blue Asbestos.— $\text{NaFe}(\text{SiO}_3)_2\text{FeSiO}_3$ . Long delicate easily separable blue fibers and massive. H., 4. Sp. gr., 3.2 to 3.3. Found in Griqualand, South Africa; Golling, Tyrol; Cumberland, R. I., and elsewhere.

## GARNET.

**COMPOSITION.**— $\text{R}''_2\text{R}'''_2(\text{SiO}_4)_3$ .  $\text{R}''$  is Ca, Mg, Fe or Mn.  $\text{R}'''$  is Al, Fe''' or Cr, rarely Ti.

**GENERAL DESCRIPTION.**—Imbedded isometric crystals, either complete or in druses and granular, lamellar and compact masses. Usually of some brown, red or black color, but occurring of all colors except blue, and harder than quartz. Also found in alluvial material as rounded grains.

---

\* "Common hornblende consists of  $(\text{Ca.Mg.Fe.Na K H Al.Fe})\text{SiO}_3$ , in which Ca is about one quarter of all the bases." "So-called *basaltic hornblende* is richer in ferric iron than *common hornblende*." Iddings, "Rock Minerals," p. 336.

CRYSTALLIZATION. — Isometric. Usually a combination of the dodecahedron  $d$  and the tetragonal trisoctahedron,  $n = (a : 2a : 2a)$ ;

FIG. 511.

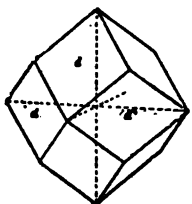


FIG. 512.

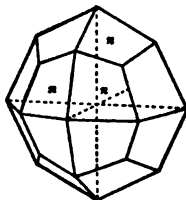
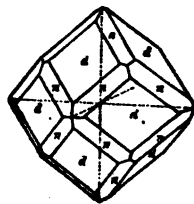


FIG. 513.



$\{211\}$ , Fig. 513, or these as simple forms, Figs. 511, 512, or more rarely with the hexoctahedron,  $s = (a : \frac{2}{3}a : 3a)$ ;  $\{321\}$ , Fig. 164. **Optical Characters.**

Isotropic but often with local weak double refraction. Index of refraction 1.739 to 1.878, hence in balsam the surface appears very rough.

**Physical Characters.** H., 6.5 to 7.5. Sp. gr.,\* 3.15 to 4.38.

LUSTRE, vitreous or resinous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle to tough.

COLOR, brown, black, violet, yellow, red, white, green.

CLEAVAGE, dodecahedral, imperfect.

**BEFORE BLOWPIPE, ETC.**—Fuses rather easily to light brown glass, except in case of infusible chromium and yttrium varieties. Insoluble before fusion, but after fusion will usually gelatinize with hydrochloric acid. Bead reactions vary with composition.

#### VARIETIES.

*Grossularite*.— $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ . White, pale yellow, pale-green, brown-red rose-red.

*Pyrope*.— $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ . Deep-red to nearly black, often transparent.

*Almandite*.— $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ . Fine deep-red to black. Includes part of precious and of common garnet.

*Spessartite*.— $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$ . Brownish-red to purplish hyacinth red.

*Andradite*.— $\text{Ca}_3\text{Fe}_3(\text{SiO}_4)_3$ . Yellow, green, red, brown, black. Includes many of the common garnets.

*Uvarovite*.— $\text{Ca}_3\text{Cr}_3(\text{SiO}_4)_3$ . Emerald green, small crystals.

*Schorlomite*.— $\text{Ca}_3(\text{Fe.Ti})_2(\text{SiTi})_4\text{O}_{12}$ . Black.

*Common Garnet* is a mixture of *grossularite*, *almandite* and *andradite*.

#### FORMATION AND OCCURRENCE OF GARNETS.

Widely distributed in all classes of rocks. Some of the occurrences are:

##### **Separations from Magma.**

*Almandite* in granite and andesite.

*Andradite* in granite and leucite-nephelite rocks.

*Spessartite* in granite and rhyolite.

*Pyrope* in peridotites and their serpentines.

##### **Contacts with Limestone.**

*Grossularite* and *andradite*.

##### **Metamorphic Rocks.**

*Grossularite* in limestones.

*Common garnet* in schists, eclogites, amphibolites, etc.

*Almandine* in schists and gneisses.

*Andradite* in gneiss and serpentine.

*Spessartite* in gneiss and quartzite.

*Ouvarovite* in serpentines.

**REMARKS.**—Important localities for gem garnet are mentioned on p. 567. In Lewis and Warren Counties, N. Y.; Rabun County, Ga., and Burke County, N. C., garnets are mined for use as an abrasive.

#### **VESUVIANITE.—Idocrase.**

**COMPOSITION.** —  $\text{Ca}_6[\text{Al}(\text{OH}, \text{F})]\text{Al}_2(\text{SiO}_4)_6$  with replacement of Ca by Mn, and Al by Fe.

**GENERAL DESCRIPTION.** — Brown or green, square or octagonal prisms and less frequently in pyramidal forms. Also in columnar masses or granular or compact.

**CRYSTALLIZATION.** — Tetragonal. Axis  $d = 0.537$ . Usually the unit prism  $m$  with base  $c$  and unit pyramid  $p$ . Prismatic faces often vertically striated. Supplement angles  $pp = 50^\circ 39'$ ;  $cp = 37^\circ 14'$ .

##### **Optical Characters.**

Uniaxial — (rarely +). Indices varying considerably but always over 1.7, hence in balsam marked relief and rough surface.  $\gamma - \alpha$ ,

0.001 to 0.006, hence very low interference colors. Basal sections yield faint cross in convergent light.

FIG. 514.

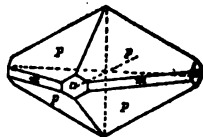


FIG. 515.

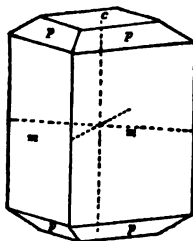
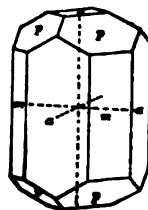


FIG. 516



Monzoni, Tyrol.

**Physical Characters.** H., 6.5. Sp. gr., 3.35 to 3.45.

LUSTRE, vitreous to resinous.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, brown or green, rarely yellow or blue Dichroic.

CLEAVAGE, indistinct, prismatic and basal.

**BEFORE BLOWPIPE, ETC.**—Fuses easily with intumescence to a green or brown glass. At high heat yields water in the closed tube. Very slightly affected by hydrochloric acid, but after ignition is dissolved leaving a gelatinous residue.

**SIMILAR SPECIES.**—The crystals and the columnar structure distinguish it from epidote, tourmaline, or garnet. The colors are not often like those of pyroxene.

**FORMATION AND OCCURRENCE.**—Chiefly in contacts as at Monzoni, Tyrol; Ala, Piedmont; Morelos, Mexico; Rumford, Maine. Also in blocks of limestone enclosed in igneous rock as at Vesuvius. Rarely in gneiss and schists and in dense aggregates in serpentine. A massive variety of vesuvianite resembling jade has been called californite.

### THE OLIVINE GROUP.

The minerals described are:

*Forsterite*  
*Chrysolite*  
*Fayalite*

$Mg_2SiO_4$   
 $(Mg, Fe)_2SiO_4$   
 $Fe_2SiO_4$

Orthorhombic  
Orthorhombic  
Orthorhombic

Other members of the group are tephroite, *hortonolite*, *knebelite* and *roeppeite*. All are orthosilicates of magnesium, calcium,

iron and manganese, and all orthorhombic with the prismatic angle about  $50^\circ$ , and the unit brachydome about  $60^\circ$ .

#### FORMATION AND OCCURRENCE OF OLIVINES.

##### Separations from Magma.

*Chrysolite* especially in the basic rocks. Dunite is nearly pure chrysolite. It is essential in peridotite and norite, common as microscopic crystals in basalt, gabbro and dolerite and as minor accessory in andesite, trachyte, volcanic ash and ejecta.

*Fayalite* in nephelin syenite, rhyolite and granite pegmatites.

##### Contact or Regional Metamorphism.

*Fosterite* in limestone.

*Chrysolite* in limestone, amphibolite, talc schist.

##### In Meteorites.

*Chrysolite*.

**FORSTERITE.**— $\text{Mg}_2\text{SiO}_4$  in white crystals or yellowish or greenish imbedded grains. H., 6 to 7. Sp. gr., 3.2.

**BEFORE BLOWPIPE, ETC.**—Unaltered. Dissolves in hydrochloric acid with separation of a jelly.

**REMARKS.**—Not common as pure material but a component of chrysolite. Occurs in ejected masses of Mt. Somma and in limestone at Kaiserstuhl, Baden, and Roxbury, Mass. In serpentine at Snarum, Norway.

#### CHRYSLITE.—Olivine, Peridot.

**COMPOSITION.**— $(\text{Mg.Fe})_2\text{SiO}_4$ .

**GENERAL DESCRIPTION.**—Transparent to translucent, yellowish-green granular masses, or disseminated glassy grains, or olive-green sand. When containing much iron, the color may be reddish-brown, or even, by alteration, opaque-brown or opaque-green. Rarely in orthorhombic crystals.

**CRYSTALLIZATION.**—Orthorhombic. Axes  $a : b : c = 0.4657 : 1 : 0.5865$ . Fig. 517 shows the pinacoids  $a$ ,  $b$  and  $c$ , the unit forms of pyramid, prism, macro and brachy dome  $m$ ,  $p$ ,  $o$  and  $d$ , the macro prism  $l = (a : 2b : \infty c)$ ;  $\{210\}$  and macro pyramid  $q = (a : 2b : c)$ ;  $\{212\}$ .

Supplement angles are  $mm = 49^\circ 57'$ ;  $pp = 40^\circ 5'$ ;  $co = 51^\circ 33'$ ;  $cd = 49^\circ 33'$ .

**Optical Characters.**

Biaxial +. Axial plane (001). Acute bisectrix  $\delta$ .  $\gamma$  1.697,  $\alpha$  1.661 hence in balsam rough with marked relief.  $\gamma - \alpha = 0.036$ , hence second or third order colors in thin sections. Extinction usually parallel to cleavage lines.

FIG. 517.

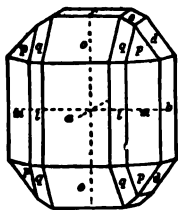


FIG. 518.



In thin rock sections, Fig. 518, the outline, the cleavage cracks, parallel (010) and (100) and the frequent partial alteration to serpentine assist in its recognition.

**Physical Characters,** H., 6.5 to 7. Sp. gr., 3.27 to 3.57.

LUSTRE, vitreous.

TRANSPARENT to translucent.

STREAK, white or yellowish.

TENACITY, brittle.

COLOR, yellowish-green to brownish-red.

**BEFORE BLOWPIPE, ETC.**—Loses color, whitens, but is infusible unless proportion of iron is large, when it fuses to a magnetic globule. Soluble in hydrochloric acid with gelatinization of silica.

**SIMILAR SPECIES.**—Differs by gelatinization from green granular pyroxene. Is harder than apatite and less fusible than tourmaline.

**VARIETIES:**

*Hyalosiderite.*—A highly ferruginous variety of chrysolite, containing sometimes as high as thirty per cent. of ferrous oxide.

*Titan-olivine*, a deep yellow or red variety from Kaiserstuhl, Baden, in basalt with about five per cent. of  $\text{TiO}_2$ ; from Pfunders, Tyrol; and Zermatt, Switzerland; in talcose schist.

**REMARKS.**—By alteration forms limonite and serpentine, and the excess of magnesia usually forms magnesite. Further change may alter the serpentine to magnesite, leaving quartz or opal. Found at Thetford, Vt., Webster, N. C., Waterville, N. H., also in Virginia, Pennsylvania, New Mexico, Oregon. Prominent foreign localities are Vesuvius and Mt. Somma, the Swedish iron deposits, the Sandwich Islands, etc.

**USES.**—Transparent varieties are sometimes cut as gems (see page 566).

**FAYALITE.**— $\text{Fe}_2\text{SiO}_4$ . In minute yellow to black crystals and massive. H., 6.5. Sp. gr., 4.32.

**BEFORE BLOWPIPE, ETC.**—Fuses easily to black magnetic globule. Gelatinizes with acids.

**REMARKS.**—Found in granite pegmatites at Mourne Mts., Ireland, and Rockport, Mass.; in nepheline syenite in Wisconsin; in volcanic rocks at Fayal, Azores; Yellowstone Park; Lipari and elsewhere.

### THE SCAPOLITE GROUP.

The scapolites are regarded as a series of isomorphous mixtures of *meionite* (Me) =  $\text{Ca}_4\text{Al}_6\text{Si}_6\text{O}_{28}$  and *marialite* (Ma),  $\text{Na}_4\text{Al}_3\text{Si}_6\text{O}_{24}\text{Cl}$ . These end members are not common, *marialite* occurring in a volcanic rock near Naples and *meionite* at Vesuvius and Lake Laach.

The species described are:

|                  |                              |            |
|------------------|------------------------------|------------|
| <b>Wernerite</b> | Me:Ma from 3 : 1 to 1 : 2    | Tetragonal |
| <b>Missonite</b> | Me : Ma from 1 to 2 to 1 : 3 | Tetragonal |

### FORMATION AND OCCURRENCE.

Not known as primary minerals in igneous rocks. Sometimes secondary.

#### Contacts.

Common in limestone contacts.

#### Metamorphic Rocks.

Common in schists and gneiss containing pyroxene or epidote, also unaltered gabbros by (pneumatolytic?) alteration of lime soda feldspars. Found in limestones.

### WERNERITE.—Scapolite.

**COMPOSITION.**—A silicate of calcium, and aluminum, of complex composition. It contains also soda and chlorine.

**GENERAL DESCRIPTION.**—Coarse, thick, tetragonal, "club-shaped," crystals, usually quite large and dull and of some gray, green, or white color. Cleavage surfaces have a characteristic fibrous appearance. Also in columnar and granular masses.

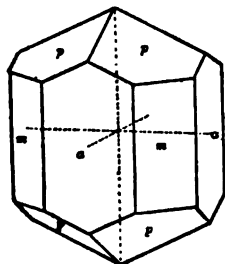
**CRYSTALLIZATION.**—Tetragonal. Class of third order pyramid, p. 47. Axis  $c = 0.438$ . Usually prisms of first order  $m$ , and second order  $a$ , and unit pyramid  $p$ . Supplement angle  $pp = 43^\circ 45'$ .



**Optical Characters.**

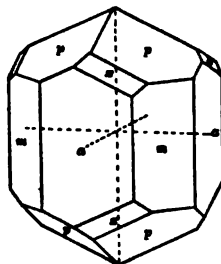
Uniaxial, —. Indices vary with composition,  $\gamma$  1.597 to 1.555,  $\alpha$  1.558 to 1.542, hence in balsam colorless grains or laths showing cleavage lines but smooth and without relief,  $\gamma - \alpha$  0.013, hence

FIG. 519.



Usual form.

FIG. 520.



Melonite of Vesuvius.

usually somewhat brilliant interference colors in thin sections. Interference figure in basal sections.

Distinguished from feldspars by absence of twinning, from quartz by cleavage and from both by higher interference colors.

**Physical Characters.** H., 5 to 6. Sp. gr., 2.66 to 2.73.

LUSTRE, vitreous to dull.

OPAQUE to translucent.

STREAK, white.

TENACITY, brittle.

COLOR, gray, green, white, bluish, reddish.

CLEAVAGE, parallel to both prisms.

**BEFORE BLOWPIPE, ETC.**—Fuses with intumescence to a white glass containing bubbles. Imperfectly soluble in hydrochloric acid.

**SIMILAR SPECIES.**—Crystals often resemble those of pyroxene; the angles of the terminal planes are conclusive. Massive material resembles feldspar, but has a characteristic fibrous appearance on the cleavage and is more fusible.

**REMARKS.**—Especially abundant at Bolton and other localities in Mass., and in northern New York and Canada. Other prominent localities are Pargas, Finland; Arendal, Norway; and Lake Baikal.

**MIZZONITE. Dipyre.**—With 54 to 57 p. c.  $\text{SiO}_2$ , corresponding to  $\text{Me} : \text{Ma} = 1 : 2$  to  $\text{Me} : \text{Ma} = 1 : 3$ .

In slender square prisms with essentially the characters of wernerite.

Found at Vesuvius; in the Pyrenees; at Bamle, Norway; Canaan, Conn.; and Ripon, Quebec

### THE ANDALUSITE GROUP.

The minerals described are:

|                    |                                     |              |
|--------------------|-------------------------------------|--------------|
| <b>Andalusite</b>  | $\text{Al}(\text{AlO})\text{SiO}_4$ | Orthorhombic |
| <b>Sillimanite</b> | $\text{Al}(\text{AlO})\text{SiO}_4$ | Orthorhombic |
| <b>Cyanite</b>     | $(\text{AlO})_2\text{SiO}_5$        | Triclinic    |

These minerals with identical chemical composition, for which the simplest empirical formula would be  $\text{Al}_2\text{SiO}_5$ , are generally regarded as different in chemical structure and the formulæ written as above. Sillimanite is the most stable under the action of heat, the others changing to it.

#### FORMATION AND OCCURRENCE OF ANDALUSITE GROUP.

##### In Igneous Rocks.

*Sillimanite* and *andalusite* occasionally occur in granite, but according to Iddings\* the *andalusite* is accompanied by inclusions of sedimentary rock.

##### Contacts.

*Andalusite* (*chiastolite*) usually without *sillimanite* in contact zone of schists and slates with intrusions. *Cyanite* occasional.

##### Metamorphic Rocks.

*Andalusite*, *sillimanite* and *cyanite* in some gneisses and mica schists.

#### OPTICAL DETERMINATION OF THE ANDALUSITE GROUP.

All are biaxial and with high indices showing in balsam high relief and rough surface.

Useful characters may tabulate as follows:

|                  | Elongation. | Indices Refraction. |          |                   | Usual Appearance in Sections.        |
|------------------|-------------|---------------------|----------|-------------------|--------------------------------------|
|                  |             | $\gamma$            | $\alpha$ | $\gamma - \alpha$ |                                      |
| Andalusite.....  | —           | 1.643               | 1.632    | 0.011             | Short prisms, square sections.       |
| Sillimanite..... | +           | 1.676               | 1.656    | 0.021             | Slender needles and aggregates,      |
| Cyanite.....     | —           | 1.729               | 1.717    | 0.011             | Bladed crystals, six-sided sections. |

Between each other the appearance, the sign of elongation, the relatively bright interference colors of sillimanite and the large-angled interference figure and oblique ( $30^\circ$ ) extinction on the easy

\* *Rock Minerals*, p. 290.

cleavage (100) of cyanite, generally suffice. The symmetrically arranged carbonaceous inclusions in andalusite, Fig. 217, and the needle aggregates of *sillimanite* Fig. 521 also assist.

FIG. 521.



Sillimanite needle aggregate.

In both andalusite and sillimanite the axial plane is (010) and the acute bisectrix is  $c'$ , the former giving a very large angle, the latter a small angle.

#### ANDALUSITE.—Chiaistolite.

COMPOSITION.— $\text{Al}(\text{AlO})\text{SiO}_4$ , ( $\text{Al}_2\text{O}_3$ , 63.2,  $\text{SiO}_2$ , 36.8 per cent.)

GENERAL DESCRIPTION.—Coarse, nearly square prisms of pearl gray or pale red color, or in very tough, columnar or granular masses. An impure soft variety (chiaistolite) occurs in rounded prisms, any cross section of which shows a cross or checkered figure, due to the symmetrical deposition of the impurities, p. 80.

FIG. 522.

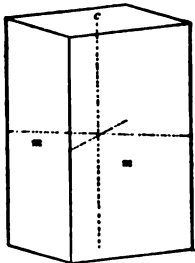
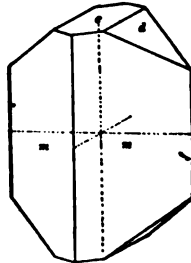


FIG. 523.



**CRYSTALLIZATION.**—Orthorhombic. Axes  $a:b:c = 0.986:1:0.702$ . Usually either the unit prism  $m$ , and base  $c$ , or these with the unit brachy dome  $d$ . Supplement angles are  $mm = 89^\circ 12'$ ,  $dd = 70^\circ 10'$ .

**Physical Characters.** H., 7 to 7.5. Sp. gr., 3.16 to 3.20.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle to tough.

COLOR, rose-red, flesh-red, violet, pale green, white, pearl-gray.

CLEAVAGE, prismatic, imperfect at angle of  $90^\circ 48'$

**BEFORE BLOWPIPE, ETC.**—Infusible. In powder becomes blue with cobalt solution. Insoluble in acids.

**REMARKS.**—It occurs as stated on p. 517. It alters rather readily to cyanite or kaolin. Found in many localities in the New England States, also in Pennsylvania and California. It has been recognized in granite in Cornwall and Saxony. Large crystals are found at Lisens, Tyrol, and transparent crystals in Minas Geraes, Brazil.

#### SILLIMANITE or FIBROLITE.

**COMPOSITION.**— $\text{Al}(\text{AlO})\text{SiO}_4$ .

**GENERAL DESCRIPTION.**—Long, almost fibrous orthorhombic crystals, and fibrous or columnar masses of brown or gray color.

**PHYSICAL CHARACTERS.**—Transparent to translucent. Lustre, vitreous. Color, brown, gray, greenish. Streak, white. H., 6 to 7. Sp. gr., 3.23 to 3.24. Tough. Cleavage, parallel to brachy pinacoid.

**BEFORE BLOWPIPE, ETC.**—Infusible, becomes dark blue with cobalt solution. Insoluble in acids.

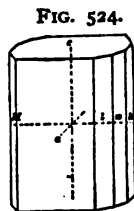
**REMARKS.**—Chiefly found in mica schist, gneiss, etc. Sometimes with andalusite.

**USES.**—In the stone age it was used for tools, weapons, etc., being second only to jade in toughness.

#### CYANITE. — Kyanite.

**COMPOSITION.**— $(\text{AlO})_2\text{SiO}_5$ , probably a basic metasilicate.

**GENERAL DESCRIPTION.**—Found in long blade-like triclinic crystals, rarely with terminal planes. The color is a blue, deeper along the center of the blades, and at times passes into green or white.



**Physical Characters.** H., 5 to 7. Sp. gr., 3.56 to 3.67.

LUSTRE, vitreous.

TRANSLUCENT to transparent.

STREAK, white.

TENACITY, brittle.

COLOR, blue, white, gray, green to nearly black.

CLEAVAGE, parallel to the three pinacoids.

BEFORE BLOWPIPE, ETC.—Infusible, with cobalt solution becomes blue. Insoluble in acids.

### STAUROLITE.

COMPOSITION.— $\text{Fe}(\text{AlO})_4(\text{AlOH})(\text{SiO}_4)_n$ , but varying. May contain Mg or Mn.

GENERAL DESCRIPTION.—Dark brown to nearly black orthorhombic prisms often twinned, or in threes, crossing at  $90^\circ$  and  $120^\circ$ . Surfaces bright if unaltered. Very hard.

CRYSTALLIZATION.—Orthorhombic. Axes  $a : \bar{b} : c = 0.473 : 1 : 0.683$ . Usual forms: unit prism  $m$ , unit dome  $o$  and pinacoids  $b$  and  $c$ . Frequently in twins crossed nearly at right angles, Fig. 566, or nearly at  $60^\circ$ , Fig. 567.

Supplement angles are:  $mm = 50^\circ 40'$ ;  $co = 55^\circ 14'$ .

#### Optical Characters.

Biaxial +, axial plane (100), acute bisectrix  $c'$ , hence interference figure (large angle) in basal section.

Indices of refraction high,  $\gamma = 1.746$ ,  $\alpha = 1.736$ , hence marked relief in balsam.  $\gamma - \alpha = 0.010$ , hence interference colors like quartz. *Extinctions* parallel or symmetrical to outlines. Elongation +. Distinctly pleochroic in shades of brown.

FIG. 525.

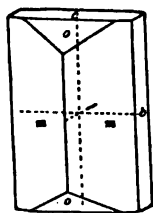


FIG. 526.

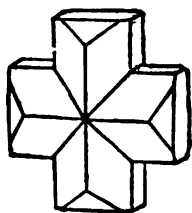
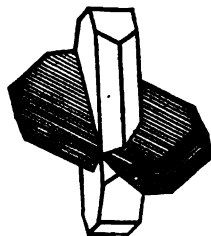


FIG. 527.



Physical Characters. H., 7 to 7.5. Sp. gr., 3.65 to 3.75.

LUSTRE, resinous or vitreous.

TRANSLUCENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, dark brown, blackish-brown, gray when weathered.

BEFORE BLOWPIPE, ETC.—Infusible, except when manganiferous. Partially soluble in sulphuric acid.

REMARKS.—Occurs chiefly in gneiss and mica schist; and rarely as a contact mineral in clay slates. Abundant at Claremont, Grantham, and Lisbon, N. H.,

at Windham, Me., Chesterfield, Mass., Litchfield, Conn., and several other localities in New England. Also in New York, North Carolina, Georgia, and Pennsylvania. Foreign localities are Mt. Campione, Switzerland; Greiner, Tyrol; Brittany; Ireland.

### BERYL, TOPAZ AND TOURMALINE.

|                   |  |              |
|-------------------|--|--------------|
| <b>Beryl</b>      | $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$         | Hexagonal    |
| <b>Topaz</b>      | $\text{Al}(\text{Al}(\text{O.F}_2))\text{SiO}_4$ | Orthorhombic |
| <b>Tourmaline</b> | $\text{R}_{12}\text{B}_2(\text{SiO}_3)_4$        | Hexagonal    |

While not a group in any chemical or crystallographic sense, the minerals are conveniently discussed together as to formation and occurrence and optical properties.

#### FORMATION AND OCCURRENCE.

Topaz and tourmaline are due to pneumatolytic action; beryl is so in part, perhaps wholly. They occur often associated. The chief occurrences are:

##### Igneous Rocks.

*Beryl, topaz and tourmaline* in granites and especially in pegmatites. Examples: Mourne Mt., Ireland; Elba, Finbo, Sweden; Black Hills, Dakota; Grafton, N. H.

*Topaz* in Rhyolite, Nathrop, Colorado; Thomas Range, Utah.

##### Contacts.

*Iron tourmaline* between schists and granites.

*Magnesium tourmaline* in limestone contacts.

##### Veins.

*Topaz and tourmaline* almost invariably present in tin veins and common in other high temperature deposits.

*Beryl (emerald)* of Muzo, Colombia, in calcite veins in sediments, probably derived from nearby pegmatites.

##### Replacements.

*Topaz* metasomatically replaces country rock, forming topaz rocks near the tin veins of Schneckenstein, Saxony; and Mount Bischoff, Tasmania.

*Tourmaline* similarly in tin regions, as at Cornwall, replaces mica and feldspar, forming tourmaline granites, luxullianite, etc.

##### Metamorphic Rocks.

*Beryl and tourmaline* occur in mica schists, and gneiss and *tourmaline* in clay slates.

---

\* Beyschlag, Vogt and Krusch (Truscott), p. 415.

## OPTICAL CHARACTERS.

|              |              | $\gamma$       | $\alpha$       | $\gamma - \alpha$ | Elonga-<br>tion. |
|--------------|--------------|----------------|----------------|-------------------|------------------|
| Beryl.....   | Uniaxial (-) | 1.572 to 1.578 | 1.567 to 1.573 | 0.006             | (-)              |
| Topaz.....   | Biaxial (+)  | 1.617 to 1.637 | 1.609 to 1.629 | 0.008             | (+)              |
| Tourmaline:  |              |                |                |                   |                  |
| Lithium..... | Biaxial (-)  | 1.637 to 1.650 | 1.620 to 1.625 | 0.014 to 0.021    | (-)              |
| Magnesium... | Biaxial (-)  | 1.631 to 1.653 | 1.612 to 1.629 | 0.019 to 0.024    | (-)              |
| Iron.....    | Biaxial (-)  | 1.642 to 1.685 | 1.622 to 1.651 | 0.020 to 0.034    | (-)              |

For topaz the axial plane is the easy basal cleavage .001 and the acute bisectrix is  $\hat{c}$ .

In thin sections in balsam relief is low in beryl, medium in topaz, marked in tourmaline.

Interference colors in thin sections are evidently very low in *beryl*, about like quartz in *topaz* and while bright in tourmaline may be masked by the strong absorption (greatest at right angles to  $\hat{c}$ ).

Pleochroism is strong in tourmaline and little noticed in the others.

## BERYL. — Emerald, Aquamarine.

COMPOSITION.\* —  $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ .

GENERAL DESCRIPTION. — Hexagonal prisms, from mere threads to several feet in length. Usually some shade of green. Sometimes in large columnar or granular masses. Harder than quartz.

FIG. 528.

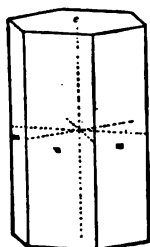


FIG. 529.

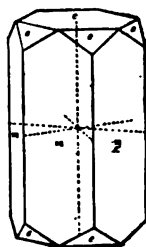
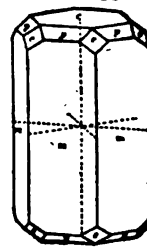


FIG. 530.



CRYSTALLIZATION. — Hexagonal. Axis  $\hat{c} = 0.499$ . Usually prism  $m$  with base  $c$ , sometimes with unit pyramid  $p$  or second order form  $e = (2a : 2a : a : 2c)$ ;  $\{11\bar{2}1\}$ . Supplement angles  $c\hat{p} = 29^\circ 56'$ ;  $ce = 44^\circ 56'$ .

\* Sodium, lithium and cesium may replace beryllium.

**Physical Characters.** H., 7.5 to 8. Sp. gr., 2.63 to 2.8.

LUSTRE, vitreous.

TRANSPARENT to nearly opaque.

STREAK, white.

TENACITY, brittle.

COLOR, emerald to pale-green, blue, yellow, white, red, colorless.

CLEAVAGE, imperfect basal and prismatic.

**BEFORE BLOWPIPE, ETC.**—Fuses on thin edges, often becoming white and translucent. Slowly dissolved in salt of phosphorus to an opalescent bead. Insoluble in acids.

#### VARIETIES.

*Emerald*.—Bright emerald green, from the presence of a little chromium.

*Aquamarine*.—Sky-blue to greenish-blue.

*Goshenite*.—Colorless.

**SIMILAR SPECIES.**—Harder than apatite, quartz or tourmaline. Differs in terminal planes from quartz and in form from chrysoberyl. Lacks distinct cleavage of topaz. Rarely massive. Usually some shade of green.

**REMARKS.**—Beryls are especially abundant at Acworth and Grafton, \* N. H.; Royalston, Mass.; Paris and Stoneham, Me.; Alexander County, N. C.; the Black Hills of South Dakota, and Litchfield, Conn. Famous foreign localities are Muzo, Colombia; the Urals, Brazil, India and Australia.

**USES.**—Emerald and aquamarine are cut as gems (see p. 559).

### TOPAZ.

**COMPOSITION.**— $\text{Al}_2\text{Si}_2\text{O}_7\text{F}_{10}$  or  $\text{Al}(\text{Al}(\text{O.F.}))\text{SiO}_4$ .

**GENERAL DESCRIPTION.**—Hard, colorless or yellow transparent orthorhombic crystals with easy basal cleavage. Also massive in columnar aggregates, and as rolled fragments and crystals in alluvial deposits.

**CRYSTALLIZATION.**—Orthorhombic.  $a:b:c = 0.529:1:0.477$ .

Prisms often vertically striated. Crystals rarely doubly terminated. The predominating forms are the unit prism  $m$ , brachy prism  $l = (2a:b:\infty c)$ ;  $\{120\}$  (with predominance of  $l$  the section is often nearly square); base  $c$ , unit pyramid  $p$  and dome  $f = (\infty a:b:2c)$ ;  $\{021\}$ .

Supplement angles are:  $mm = 55^\circ 43'$ ;  $ll = 93^\circ 11'$ ;  $pp = 38^\circ$ ;  $ff(\text{top}) = 87^\circ 18'$ .

\* Those at Acworth and Grafton are sometimes of immense size. One crystal, near the railroad station of Grafton Centre, measures 3 feet 4 inches by 4 feet 3 inches on horizontal section, and is exposed for over 5 feet.



FIG. 531.

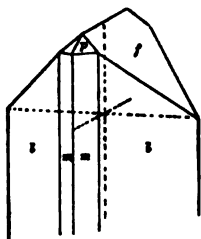


FIG. 532.

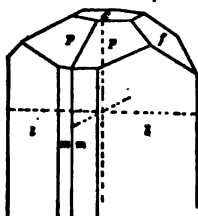
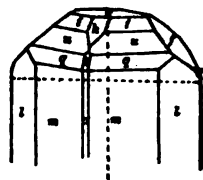


FIG. 533.



Omi, Japan.

**Physical Characters.** H., 8. Sp. gr., 3.4 to 3.65.

LUSTRE, vitreous.

TRANSPARENT to nearly opaque.

STREAK, white.

TENACITY, brittle.

COLOR, colorless, yellow, pale-blue, green, white, pink.

CLEAVAGE, basal perfect.

**BEFORE BLOWPIPE, ETC.**—Infusible, but yellow varieties may become pink. With cobalt solution the powder becomes blue. Slowly dissolved in borax. If powdered and heated with previously fused salt of phosphorus in open tube the glass will be etched. Insoluble in acids.

**REMARKS.**—Fine crystals are obtained in Colorado, Utah, and Maine and well-known foreign localities are Minas Geraes, Brazil; the Urals; Mexico; Japan, and the tin mines of Saxony.

For topaz as a gem mineral see page 564.

### TOURMALINE.—Schorl.

**COMPOSITION.**— $R_{18}B_3(SiO_3)_6$ . R chiefly Al, K, Mn, Ca, Mg, Li.

**GENERAL DESCRIPTION.**—Prismatic crystals, the cross sections of which frequently show very prominently a triangular prism. Color, usually some dark smoky or muddy tint of black, brown or blue, also bright green, red, and blue, or rarely colorless. Sometimes the centre and outer shell are different colors, as red and green. Sometimes the color is different at two opposite ends. Occurs also columnar in bunches or radiating aggregates and in compact masses.

**CRYSTALLIZATION.**—Hexagonal. Hemimorphic class, p. 52. Axis  $c = 0.448$ .

Prevailing forms: trigonal prism  $m$ , second order prism  $a$ , trigonal pyramids  $p$  (unit) and  $f = (a : \infty a : a : 2c)$ ,  $\{2021\}$ . Supplement angles are:  $pp = 46^\circ 52'$ ;  $ff = 77^\circ$ ;  $mp = 62^\circ 40'$ .

FIG. 534.

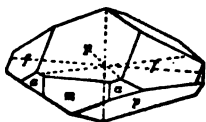


FIG. 535.

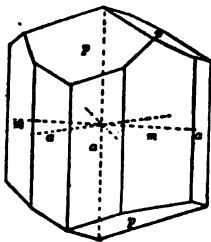
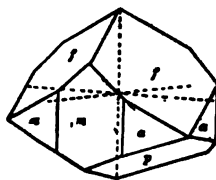


FIG. 536.



**Physical Characters.** H., 7 to 7.5. Sp. gr., 2.98 to 3.20.

LUSTRE, vitreous or resinous. TRANSPARENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, black, brown, green, blue, red, colorless.

CLEAVAGE, difficult, parallel to  $R$  and  $i-2$ .

**BEFORE BLOWPIPE, ETC.**—Usually fuses, sometimes very easily. With a paste of  $\text{KHSO}_4$ ,  $\text{CaF}_2$ , and water it yields a green flame. Insoluble in acids, but after strong ignition gelatinizes.

**SIMILAR SPECIES.**—Differs from hornblende in hardness, crystalline form and absence of prismatic cleavage. Differs from garnet or vesuvianite in form, difficult fusion, and green flame.

**REMARKS.**—The chemical formula is not decided. Others suggested are  $\text{Al}_2\text{R}'_2\text{Si}_6\text{B}_2\text{O}_{21}$ .  $\text{Al}_2\text{R}'_4\text{Si}_6\text{B}_2\text{O}_{21}$ .  $\text{Al}_2\text{R}'_6\text{Si}_6\text{B}_2\text{O}_{21}$ . Strictly tourmaline represents an isomorphous group with three great types.

**Iron Tourmaline.**—The common black variety, which alone is important as a rock-making mineral. Associated commonly with muscovite or biotite.

**Magnesium Tourmaline.**—Often found in limestone or dolomite, with phlogopite as the accompanying mica.

**Alkali Tourmaline.**—Contains lithium or sodium, sometimes potassium in less amount. Found in pegmatites, with muscovite and lepidolite. Often transparent red, green, blue, etc.

Famous localities are Gouverneur and Pierrepont, N. Y.; Paris and Hebron, Maine; Pala, California; foreign localities are Urals, Brazil, Elba and Carinthia.

For tourmaline as a gem mineral, see p. 564.

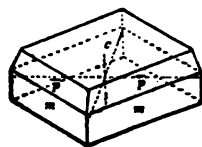
### TITANITE. — Sphene.

**COMPOSITION.** —  $\text{CaSiTiO}_5$ .

**GENERAL DESCRIPTION.** — Brown, green or yellow, wedge-shaped or tabular monoclinic crystals, with adamantine or resinous lustre.

**CRYSTALLIZATION.** — Monoclinic.  $\beta = 60^\circ 17'$ . Axes  $a : b : c = 0.755 : 1 : 0.854$ . Crystals very varied. The most common forms are: pinacoids  $c$  and  $a$ , unit prism  $m$ , negative unit pyramid  $\bar{p}$ , domes  $x = (a : \infty b : \frac{1}{2}c)$ ;  $\{102\}$ , and  $s = (\infty a : b : 2c)$ ;  $\{021\}$ , and the pyramid  $l = (a : b : \frac{1}{2}c)$ ;  $\{112\}$ . Supplement angles are:  $mm = 66^\circ 29'$ ;  $pp = 43^\circ 49'$ ;  $ll = 46^\circ 7'$ .

FIG. 537.



Diana, N. Y.

### Optical Characters.

Biaxial +. Axial plane (010). Interference figure characterized by large differences in axial angle for different colors, and broad rainbows instead of black hyperbola.

Indices very high,  $\gamma$  2.009,  $\alpha$  1.887,  $\gamma - \alpha$ , 0.1214. In sections interference colors usually very high but in some sections grays of 1° order. Extinction angles not characteristic.

**Physical Characters.** H., 5 to 5.5. Sp. gr., 3.4 to 3.56.

LUSTRE, adamantine or resinous. TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, brown to black, yellow, green, rarely rose-red.

CLEAVAGE, prismatic easily, pyramidal less easily.

**BEFORE BLOWPIPE, ETC.**—Fuses, with intumescence, to a dark glass, sometimes becoming yellow before fusion. In salt of phosphorus after reduction, the bead is violet. Partly soluble in hydrochloric acid, completely so in sulphuric acid.

**FORMATION AND OCCURRENCE**—Crystallizes from magma as accessory mineral chiefly in the plutonic rocks, such as hornblende, granite, syenite, and elæolite-syenite, but also in trachytes, etc.

Secondary in metamorphic rocks, in rocks carrying rutile or ilmenite, in clefts, gneiss, or schists or in granular limestone.

**REMARKS.**—Famous localities are Tavetsch, Switzerland; Pfitsch, Tyrol; Renfrew, Ontario, and other Canadian apatite veins; Diana, New York; Brewsters, N. Y.; Bridgewater, Pa., and Magnet Cove, Ark.

For titanite as a gem see p. 566.

## THE EPIDOTE GROUP.

The minerals described are:

|                    |   |              |
|--------------------|---|--------------|
| <i>Zoisite</i>     | $\text{Ca}_2\text{Al}_2(\text{Al.OH})(\text{SiO}_4)_3$              | Orthorhombic |
| <i>Epidote</i>     | $\text{Ca}_2\text{Al}_2(\text{Al.OH})(\text{SiO}_4)_3$              | Monoclinic   |
| <i>Piedmontite</i> | $\text{Ca}_2(\text{Al.Mn})_2(\text{Al.OH})(\text{SiO}_4)_3$         | Monoclinic   |
| <i>Allanite</i>    | $(\text{Ca.Fe})_2(\text{Al.Ce.Fe})_2(\text{Al.OH})(\text{SiO}_4)_3$ | Monoclinic   |

## FORMATION AND OCCURRENCE OF EPIDOTE GROUP.

**Separation from Magma.**

*Allanite* is an accessory mineral in granite, pegmatites, and in other igneous rocks in minor amounts.

*Epidote* is rare but sometimes is found intergrown with allanite and occasionally alone, as in granite of Ilchester, Md.

**Secondary in Igneous Rocks.**

*Epidote* is widely distributed as an alteration of the feldspars and other minerals rich in calcium, *piedmontite* is secondary in the original locality, the *zoisite* in Piedmont granite is probably secondary and it accompanies epidote in altered gabbros (saussurite).

**Contacts.**

*Epidote* in contacts with limestone and other rocks high in calcium.

**Metamorphic Rocks.**

*Zoisite* is especially found in metamorphosed igneous rocks high in calcium, as amphibolite or glaucophane schist.

*Epidote* is common in clefts and hollows of gneiss and schists (forms with quartz the rock epidosite).

**Ore Beds.<sup>3</sup>**

*Zoisite* in sulphides, *epidote* rarely.

## OPTICAL DETERMINATION OF EPIDOTE GROUP.

The ready distinctions between members of the group lie in the color, pleochroism, interference colors and extinctions.

|                  | Color.                                       | Pleochroism.      | Interference Colors. | Extinctions with Cleavages. |
|------------------|--|-------------------|----------------------|-----------------------------|
| Zoisite . . . .  | Colorless                                    | None              | Very low order       | Parallel                    |
| Epidote . . . .  | { Yellowish to<br>yellow-brown<br>greenish } | Strong if colored | Often high orders    | Varying angle               |
| Piedmontite .    | Red  | Red to yellow     |                      |                             |
| Allanite . . . . | Brown  | Strong            | Medium               | Varying angle               |

In general high relief and rough surface. All are biaxial. *Epidote* differs from pyroxene in the fact that the plane of the optic axis is perpendicular to the cleavage cracks.

**ZOISITE. — Thulite.**

**COMPOSITION.** —  $\text{Ca}_2\text{Al}_2(\text{AlOH})(\text{SiO}_4)_2$ .

**GENERAL DESCRIPTION.** — Gray or green and rose red (thulite) columnar and fibrous aggregates. More rarely, deeply striated orthorhombic prisms with indistinct terminations and perfect cleavage parallel to the brachy-pinacoid.

**PHYSICAL CHARACTERS.** — Transparent to opaque. Lustre, vitreous to pearly. Color, white, gray, brown, green, pink and red. Streak, white. H., 6–6.5. Sp. gr., 3.25–3.35. Optically +.

**BEFORE BLOWPIPE, ETC.** — Swells up and fuses easily to a glassy mass which does not readily assume globular form. Not affected by HCl before ignition, but after ignition it is decomposed with formation of jelly.

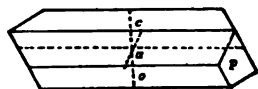
**REMARKS.** — Found at Ducktown, Tenn., Chesterfield, Mass., Uniontown, Pa., and many other localities.

**EPIDOTE.**

**COMPOSITION.** —  $\text{Ca}_2\text{Al}_2(\text{AlOH})(\text{SiO}_4)_2$ , with some iron replacing aluminum.

**GENERAL DESCRIPTION.** — Coarse or fine granular masses of peculiar yellowish-green (pistache green) color, sometimes fibrous. Also in monoclinic crystals and columnar groups, from yellow-green to blackish-green in color.

FIG. 538.



**CRYSTALLIZATION.** — Monoclinic.  $\beta = 64^\circ 37'$ . Axes  $a : b : c = 1.579 : 1 : 1.804$ . Common forms :  $m$  = unit prism,  $a$  and  $c$  pinacoids,  $p$  unit pyramid and  $o$  unit dome. Supplement angles are  $mm = 109^\circ 56'$ ;  $ca = 64^\circ 37'$ ;  $co = 63^\circ 42'$ . Crystals extended in the direction of the ortho-axis, in the zone of which are two cleavages (001) and (100) at  $64^\circ 37'$  to each other.

**Physical Characters.** H., 6 to 7. Sp. gr., 3.25 to 3.5.

**LUSTRE,** vitreous.

**TRANSPARENT** to opaque.

**STREAK,** white.

**TENACITY,** brittle.

**COLOR,** yellowish-green to nearly black and nearly white, also red and gray.

**CLEAVAGE,** basal, easy.

**BEFORE BLOWPIPE, ETC.** — Fuses easily with intumescence to a dark, usually slightly magnetic, globule. At high heat yields water. Slightly soluble in hydrochloric acid, but if previously ignited, it dissolves, leaving gelatinous silica.

**REMARKS.** — Famous localities for crystallized epidote are Untersulzbachthal, Tyrol; Bourg d'Oisans, Dauphiny; Warren, N. H.; Alaska.

**PIEDMONTITE.** — Similar in angle to epidote, but with 5 to 15 p. c.  $\text{Mn}_2\text{O}_3$ . Color reddish brown and reddish black. H. = 6.5. G. = 3.404.

Known chiefly in the occurrence with braunite at St. Marcel, Piedmont, and the piedmontite schists of Japan.

#### ALLANITE.

**COMPOSITION.**—Analogous to epidote, but a silicate of the cerium and yttrium groups with lime and iron.

**GENERAL DESCRIPTION.**—Pitch black or brownish embedded veins and masses and flat tabular or prismatic (like a nail) monoclinic crystals.

**PHYSICAL CHARACTERS.**—Opaque. Lustre, submetallic or pitch-like. Color, pitch black or brown. Streak, nearly white. H., 5.5 to 6. Sp. gr., 3.5 to 4.2. Brittle.

**BEFORE BLOWPIPE, ETC.**—Fuses very easily, becoming strongly magnetic, and at high temperature yielding water. Usually gelatinizes with hydrochloric acid, but after ignition is insoluble.

**REMARKS.**—Found in Sweden, Norway, Greenland and the Urals. In this country at Baringer Hill, Texas; Amherst Co., Virginia; South Mountain, Penn., and many other localities.

#### IOLITE.—Dichroite, Cordierite.

**COMPOSITION.**— $Mg_2(Al,Fe)_2(SiO_3)_4(SiO_2)_4$ .

**GENERAL DESCRIPTION.**—Short, six- or twelve-sided orthorhombic prisms and massive, glassy, quartz-like material. Usually blue in color. The color is often deep blue in one direction and gray or yellow in a direction at right angles with the first.

**PHYSICAL CHARACTERS.**—Transparent or translucent. Lustre, vitreous. Color, light to smoky blue, gray, violet or yellow. Dichroic. Streak, white. H., 7 to 7.5. Sp. gr., 2.6 to 2.66. Brittle. Cleaves parallel to brachy-pinacoid.

#### OPTICAL CHARACTERS.

Colorless or bluish with low relief in balsam ( $\gamma$  1.54 to 1.56). If blue is pleochroic. In thicker material pleochroism very marked.

Birefringence weak (0.009), hence colors like quartz. Extinction parallel cleavage cracks.

**BEFORE BLOWPIPE, ETC.**—Fuses with difficulty, becoming opaque. With cobalt solution becomes blue-gray. Partially soluble in acids.

**REMARKS.**—Occurs in gneiss and sometimes in granite, rarely in volcanic rocks, and is formed by contact with igneous matter. It is easily altered to a soft lamellar or fibrous material of green or yellow color, and is rarely found entirely unaltered.

### THE ZEOLITE GROUP.

The minerals described are:

#### ZEOLITES PROPER.\*

|                   |                                    |              |
|-------------------|------------------------------------|--------------|
| <b>Analcite</b>   | $NaAl(SiO_3)_2 + H_2O$             | Isometric    |
| <b>Natrolite</b>  | $Na_2Al(AlO)(SiO_3)_3 + 2H_2O$     | Orthorhombic |
| <b>Chabazite</b>  | $(Ca,Na_2)Al_2(SiO_3)_4 + 6H_2O$   | Hexagonal    |
| <b>Stibite</b>    | $H_4(Na_2Ca)Al_3(SiO_3)_4 + 4H_2O$ | Monoclinic   |
| <b>Heulandite</b> | $H_4CaAl_2(SiO_3)_6 + 3H_2O$       | Monoclinic   |
| <b>Harmotome</b>  | $BaAl_2Si_4O_{14}5H_2O$            | Monoclinic   |
| <b>Thomsonite</b> | $(CaNa_2)_2Al_4Si_4O_{16}5H_2O$    | Orthorhombic |

\* To these may be added ptilolite, mordenite, brewsterite, epistilbite, phillipsite, gismondite, laubanite, gmelinite, levynite, faujasite, edingtonite, mesolite, erionite, wellsite, and perhaps other species.

## ZEOLITE ANNEX.\*

|             |                                     |              |
|-------------|-------------------------------------|--------------|
| Apophyllite | $H_{14}K_2Ca_2(SiO_3)_{14} + 9H_2O$ | Tetragonal   |
| Pectolite   | $HNaCa_2(SiO_3)_2$                  | Monoclinic   |
| Prehnite    | $H_2Ca_2Al_2(SiO_4)_2$              | Orthorhombic |
| Datolite    | $Ca(B.OH)SiO_4$                     | Monoclinic   |

## FORMATION AND OCCURRENCE OF ZEOLITES.

The zeolites are of especial interest from their frequent connection with native copper, silver, magnetite, pyrrhotite and other ores. Their presence appears to prove formation at low temperatures and it is believed† they may represent a last stage of cooling and a crystallization from residual solutions. The occurrences are of the following types:

**Separation from Magma in Plutonic Rocks.**

*Analcite* is the chief constituent of a dike at Heron Bay, L. S., and occurs in sodalite syenite of Butte, Mont., and certain rocks of Pikes Peak, Col.

**Filling Blowholes and Crevices in Basic Lava.**

This is the principal occurrence but whether secondary entirely or largely a last stage of separation is not settled. All the species so occur, pectolite and datolite not so much in the blowholes as in veins and cavities.

**In Rocks and Ore Deposits Due to Contact.‡**

Somewhat rare but including some important iron deposits, *stilbite*, *analcite* and *datolite*.

**In Ore Deposits.**

Not common but including§ Andreasberg, Harz; Kongsberg, Norway; Arqueros, Chili; Guanajuato, Mex.; and Republic, Washington. All but *thomsonite* and *pectolite* are stated to so occur.

**Metamorphic Rocks.**

*Stilbite*, *chabazite* and *datolite* possibly more frequently than the others in gneiss and schists, rarely in serpentine.

---

\* Brought here because their mode of occurrence is like that of the zeolites and because the minerals which they resemble and from which they need to be distinguished are chiefly zeolites.

† See Lindgren, *Mineral Deposits*, pp. 395, 494, 586.

‡ *Ibid.*, p. 395.

§ Lindgren, l. c. p. 586.

### Hot Springs.

*Stilbite, chabazite, and apophyllite.* The rare zeolite *phillipsite* is about the only mineral that has been found in deep-sea dredging.

### THE OPTICAL DETERMINATION OF ZEOLITES.

The zeolites proper show little or no relief in balsam and are usually colorless, often fibrous. Prehnite, pectolite and datolite show decided relief.

Optically the minerals described may be separated in two divisions by their birefringence. In thin sections judged by interference colors.

#### BIREFRINGENCE VERY LOW. $\gamma - \alpha$ .001 to .007.

|                 | $\gamma - \alpha$ | Character.   | Extinction. | $\gamma$ | $\alpha$ |
|-----------------|-------------------|--------------|-------------|----------|----------|
| Analcite.....   | .001              | Isotropic    |             | 1.487    |          |
| Chabazite.....  | .003              | Uniaxial (-) |             | 1.485    |          |
| Harmotome.....  | .005              | Biaxial (+)  | length = Y† | 1.508    | 1.503    |
| Heulandite..... | .006              | Biaxial (+)  | varies      | 1.505    | 1.498    |
| Stilbite.....   | .007              | Biaxial (-)  | length = X  | 1.500    | 1.494    |

#### BIREFRINGENCE MODERATE OR HIGH. $(\gamma - \alpha)$ .012 to .045.

|                 |      |             |                         |       |       |
|-----------------|------|-------------|-------------------------|-------|-------|
| Natrolite.....  | .012 | Biaxial (+) | length = Z              | 1.488 | 1.475 |
| Thomsonite..... | .028 | Biaxial (+) | length = X              | 1.525 | 1.497 |
| Prehnite.....   | .033 | Biaxial (+) | cleavage lines          | 1.649 | 1.616 |
| Pectolite.....  | .038 | Biaxial (+) | length = Z              | 1.61  |       |
| Datolite.....   | .045 | Biaxial (-) | $\epsilon$ (nearly) = Z | 1.670 | 1.626 |

### ANALCITE.

COMPOSITION. —  $\text{NaAl}(\text{SiO}_3)_2 + \text{H}_2\text{O}$ .

GENERAL DESCRIPTION. — Small white or colorless trapezohedrons, Figs. 539, 540, or modified cubes, Fig. 541; rarely granular or compact with concentric structure.

FIG. 539.

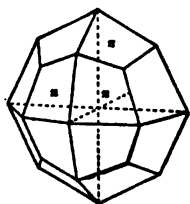


FIG. 540.

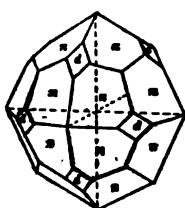
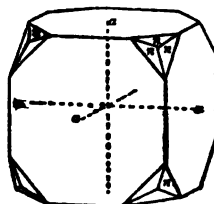


FIG. 541.



Island of Cyclops.

drons, Figs. 539, 540, or modified cubes, Fig. 541; rarely granular or compact with concentric structure.

† Hence may be *faster* or *slower* ( $\pm$ ) than the other ray according to section examined.



**CRYSTALLIZATION.**—Isometric. The trapezohedron  $n = (a : 2a : 2a)$ ;  $\{211\}$ , is most frequent sometimes modified by the cube  $a$  or dodecahedron  $d$ , and in some crystals the cube predominates.

**Physical Characters.**—H., 5 to 5.5. Sp. gr., 2.2 to 2.29.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, white, colorless, greenish, red.

**BEFORE BLOWPIPE, ETC.**—Fuses easily and quietly to a clear, colorless glass. Yields water in closed tube. Gelatinizes with hydrochloric acid.

#### **NATROLITE. — Needle Zeolite.**

**COMPOSITION.** —  $\text{Na}_2\text{Al}(\text{AlO})(\text{SiO}_3)_3 + 2\text{H}_2\text{O}$ .

**GENERAL DESCRIPTION.**—Colorless to white, slender, nearly square prisms, with very flat pyramids. Usually in radiating and interlacing clusters and bunches. Also fibrous granular and compact.

**CRYSTALLIZATION.** — Orthorhombic. Axes  $a : b : c = 0.979 : 1 : 0.354$ . Angle of prism =  $88^\circ 46'$ .

**Physical Characters.** H., 5 to 5.5. Sp. gr., 2.2 to 2.25.

LUSTRE, vitreous.

TRANSPARENT to opaque.

STREAK, white.

TENACITY, brittle.

COLOR, colorless, white, yellow, red. CLEAVAGE, prismatic.

**BEFORE BLOWPIPE, ETC.**—Fuses very easily to a colorless glass. In closed tube, yields water. Soluble in hydrochloric acid, with gelatinization.

**SIMILAR SPECIES.**—Differs from pectolite in square cross-section and fusion to a clear, colorless glass.

**REMARKS.**—Occurs with other zeolites and with prehnite, calcite and datolite.

#### **CHABAZITE.**

**COMPOSITION.** —  $(\text{Ca}, \text{Na}_2)\text{Al}_2(\text{SiO}_3)_4 + 6\text{H}_2\text{O}$ .

**GENERAL DESCRIPTION.**—Simple rhombohedral crystals, almost cubic, also in modified forms and twins. Faces striated parallel to edges. Color, white, pale-red and yellow.

**Physical Characters.** H., 4 to 5. Sp. gr., 2.08 to 2.16.  
 LUSTRE, vitreous. TRANSLUCENT, transparent.  
 STREAK, white. TENACITY, brittle.  
 COLOR, white, red, yellow. CLEAVAGE, parallel to the unit rhombohedron.

**CRYSTALLIZATION.** — Hexagonal. Scalenohedral class, p. 48. Axis  $c = 1.086$ . Unit rhombohedron  $p$  and negative rhombohedra  $e = (a : \infty a : a : \frac{1}{2}c)$ ;  $\{10\bar{1}2\}$ , and  $f = (a : \infty a : a : 2c)$ ;  $\{20\bar{2}1\}$  are most common. Supplement angles  $pp = 85^\circ 14'$ ;  $ee = 54^\circ 47'$ .

Optically — usually, sometimes + ; interference figure confused.

FIG. 542.

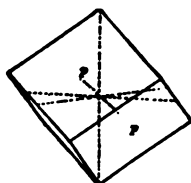


FIG. 543.

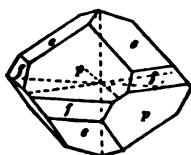


FIG. 544.



**BEFORE BLOWPIPE, ETC.** — Intumesces and fuses to a nearly white glass containing bubbles. Yields water in closed tube. Soluble in hydrochloric acid, leaving flakes and lumps of jelly.

### STILBITE. — Desmine.

**COMPOSITION.** —  $H_4(Na_2Ca) Al_2(SiO_3)_6 + 4H_2O$ .

**GENERAL DESCRIPTION.** — Tabular crystals, of white, brown or red color, pearly in lustre on broad faces and frequently united by these faces in sheaf-like groups. Sometimes globular or radiated. Crystals are orthorhombic in appearance, but really complex monoclinic twins.

FIG. 545.



Cape Blomidon, N. S.

**Physical Characters.** H., 3.5 to 4. Sp. gr., 2.09 to 2.2.  
 LUSTRE, vitreous or pearly. TRANSLUCENT.  
 STREAK, white. TENACITY, brittle.  
 COLOR, yellow, brown, white, red.  
 CLEAVAGE, parallel to pearly face.

**BEFORE BLOWPIPE, ETC.**—Swells and exfoliates in fan shapes, and fuses easily to a white, opaque glass. Yields water in closed tube. Soluble in hydrochloric acid, with a pulverulent residue.

#### HEULANDITE.

**COMPOSITION.**— $H_4CaAl_2(SiO_3)_8 + 3H_2O$ .

**GENERAL DESCRIPTION.**—Monoclinic crystals, with very bright, pearly, cleavage surfaces. The face parallel to the cleavage is also bright pearly, and is less symmetrical than the corresponding face of stilbite.

**PHYSICAL CHARACTERS.**—Transparent to translucent. Lustre, pearly and vitreous. Color, white, red, brown. H., 3.5–4. Sp. gr. 2.18–2.22. Brittle. Cleaves parallel to a pearly face.

**BEFORE BLOWPIPE, ETC.**—Exfoliates and fuses easily to a white enamel. In the closed tube yields water. Soluble in hydrochloric acid, with a residue of fine powder.

**HARMOTOME.**— $H_2(K,Ba)Al_2Si_2O_{11} + 4H_2O$ . Occurring in crossed monoclinic twins of usually white color. H., 4.5. Sp. gr., 2.44 to 2.50.

**BEFORE BLOWPIPE, ETC.**—Whitens, crumbles, fuses quietly at 3.5 to a white translucent glass. Decomposed by hydrochloric acid without gelatinizing.

**THOMSONITE.**— $(Ca.Na)_2Al_4(SiO_4)_4 + 5H_2O$ . Usually in radiating fibers or slender prismatic crystals or amygdaloidal with fibrous structure radiating from several centers and of different colors.

**BEFORE BLOWPIPE, ETC.**—Fuses with intumescence at 2 to a white enamel. Gelatinizes with hydrochloric acid.

#### APOPHYLLITE.

**COMPOSITION.**— $H_{14}K_2Ca_8(SiO_3)_{16} + 9H_2O$ , with replacement by fluorine.

**GENERAL DESCRIPTION.**—Colorless and white or pink, square crystals. Sometimes flat, square plates or approximate cubes; at other times pointed and square to nearly cylindrical in section. Notably pearly on base or may show in vertical direction a peculiar—fish eye—internal opalescence. Found occasionally in lamellar masses.

**CRYSTALLIZATION.**—Tetragonal. Axis  $c=1.252$ . Usually combinations of unit pyramid  $p$ , base  $c$ , and second order prism  $a$ . Supplement angle  $pp = 76^\circ$ ;  $cp = 60^\circ 32'$ . Prism faces vertically striated.

**Physical Characters.** H., 4.5 to 5. Sp. gr., 2.3 to 2.4.

**LUSTRE**, vitreous or pearly. **TRANSPARENT** to nearly opaque.

**STREAK**, white.

**TENACITY**, brittle.

**COLOR**, colorless, white, pink or greenish. **CLEAVAGE**, basal

**BEFORE BLOWPIPE, ETC.** — Exfoliates and fuses to a white enamel. In closed tube yields water. In hydrochloric acid forms flakes and lumps of jelly.

FIG. 546.

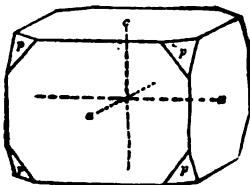


FIG. 549.

FIG. 547.

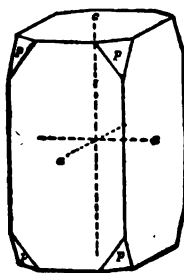
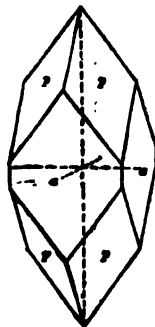


FIG. 548.



#### PECTOLITE.

**COMPOSITION.** —  $\text{HNaCa}_2(\text{SiO}_3)_2$ .

**GENERAL DESCRIPTION.** — White or gray radiating needles and fibers of all lengths up to one yard. Also in tough compact masses and rarely in monoclinic crystals.

**PHYSICAL CHARACTERS.** — Translucent to opaque. Lustre, vitreous or silky. Color, white or gray. Streak, white. H., 5. Sp. gr., 2.68 to 2.78. Brittle.

**BEFORE BLOWPIPE, ETC.** — Fuses easily to a white enamel. Yields water in closed tube. Gelatinizes with hydrochloric acid.

**REMARKS.** — Occurs with zeolites, prehnite, etc., in cavities and seams of basic eruptive rocks.

#### PREHNITE.

**COMPOSITION.** —  $\text{H}_2\text{Ca}_2\text{Al}_2(\text{SiO}_3)_3$ .

**GENERAL DESCRIPTION.** — A green to grayish-white vitreous mineral. Sheaf-like groups of tabular crystals, united by the basal planes. Sometimes barrel-shaped crystals and frequently reniform or botryoidal crusts, Fig. 270, with crystalline surface.

**Physical Characters.** H., 6 to 6.5. Sp. gr., 2.8 to 2.95.

LUSTRE, vitreous.

TRANSLUCENT.

STREAK, white.

TENACITY, brittle.

COLOR, light to dark green or grayish-white. CLEAVAGE, basal.

**BEFORE BLOWPIPE, ETC.** — Easily fusible to a whitish glass containing bubbles. In closed tube yields a little water. Soluble in hydrochloric acid, and after *fusion* is soluble with a gelatinous residue.

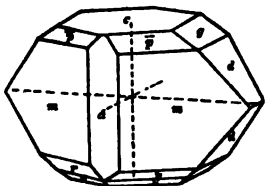
**SIMILAR SPECIES.**—Resembles calamine or green smithsonite somewhat, but is more easily fused, and does not gelatinize unless previously ignited.

### DATOLITE.

**COMPOSITION.**— $\text{Ca}(\text{B.OH})\text{SiO}_4$ .

**GENERAL DESCRIPTION.**—Highly modified, glassy, monoclinic crystals often lining a cavity in a basic rock. Usually colorless, but also white or greenish. Also in compact, dull, white or pink masses, resembling unglazed porcelain.

FIG. 550.



Bergen Hill, N. J.

FIG. 551.

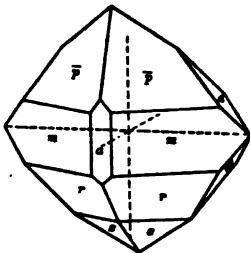
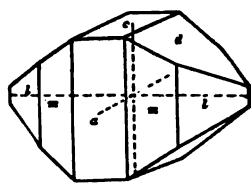


FIG. 552.



Lake Superior.

**CRYSTALLIZATION.**—Monoclinic.  $\beta = 89^\circ 51'$ . Axes  $a : b : c = 0.634 : 1 : 1.266$ . Prominent forms are the pinacoids  $a$  and  $c$ , the unit prism  $m$ , negative unit pyramid  $\bar{p}$ , unit clino-dome  $d$ , clino-prism  $l = (2a : \bar{b} : \infty c)$ ,  $\{120\}$ ; and positive hemi-pyramid  $r = (a : \bar{b} : \frac{1}{2}c)$ ,  $\{11\bar{2}\}$ . Supplement angles are  $mm = 64^\circ 47'$ ;  $ll = 76^\circ 29'$ ;  $\bar{p}\bar{p} = 59^\circ 5'$ ;  $dd = 103^\circ 23'$ .

**Physical Characters.** H., 5 to 5.5. Sp. gr., 2.9 to 3.

LUSTRE, vitreous.

TRANSLUCENT to nearly opaque.

STREAK, white.

TENACITY, brittle.

COLOR, colorless, white, greenish.

**BEFORE BLOWPIPE, ETC.**—In forceps or on charcoal fuses easily to a colorless glass, and if mixed with a flux of acid potassium sulphate and calcium fluoride and a little water it will color flame green. In closed tube yields water at a high heat. Soluble in hydrochloric acid, with gelatinization.

**SIMILAR SPECIES.**—Differs from the zeolites in crystalline form and flame and from colemanite by gelatinization.

## THE MICA GROUP.

The minerals described are:

|                   |                                 |                   |
|-------------------|---------------------------------|-------------------|
| <b>Muscovite</b>  | $H_2(K.Na)Al_2(SiO_4)_3$        | <b>Monoclinic</b> |
| <b>Biotite</b>    | $(H.K)_2(Mg.Fe)_2Al_2(SiO_4)_3$ | <b>Monoclinic</b> |
| <b>Phlogopite</b> | $R_2Mg_2Al(SiO_4)_3$            | <b>Monoclinic</b> |
| <b>Margarite</b>  | $H_2CaAl_2Si_2O_{12}$           | <b>Monoclinic</b> |

The micas are characterized by the very perfect basal cleavage, the cleavages are usually elastic but in *margarite* slightly brittle. They occur in lamellar and scaly masses and sometimes in monoclinic crystals easily mistaken for hexagonal or orthorhombic.

## FORMATION AND OCCURRENCE OF THE MICAS.

## Separation from Magma.

*Biotite* very common, disseminated in granite, syenite, diorite, trachyte, andesite, gabbro, peridotite, the best crystals are in volcanic ejecta, large plates sometimes occur in granite.

*Muscovite*.—Alone or more frequently with biotite as an important constituent of many granites and some quartz porphyries but not in recent volcanic rocks.

*Phlogopite*.—In some peridotites and leucite lavas.

## In Pegmatites.

*Muscovite, phlogopite, lepidolite.*

## Contact Metamorphism.

*Biotite, muscovite* common, *phlogopite* in dolomitic limestone.

*Margarite* in rocks high in alumina as at Crugers Point, N. Y., with staurolite and tourmaline.

## Metamorphic Rocks.

*Biotite* in gneisses and schists in large amounts.

*Muscovite* is very common in mica schists and gneiss. The secondary variety *sericite*, formed by the alteration of feldspars, quartz porphyries, and various silicates carrying aluminum, often forms schists, frequently mistaken for talcose schist.

*Paragonite*, forming schists in Switzerland and Tyrol.

*Phlogopite* in granular limestones and serpentine.

*Margarite* is invariably associated with corundum and emery as if formed from them.

## OPTICAL DETERMINATION OF THE MICAS.

The tests are on basal or transverse sections.

**Transverse Sections.**

Often lath-like with parallel cleavage cracks. When the plane of the lower nicol is parallel to these cracks there is:

*With one nicol.*—Maximum absorption and pleochroism. Indices ranging 1.57 to 1.64, but overlapping so as not to be distinctive.

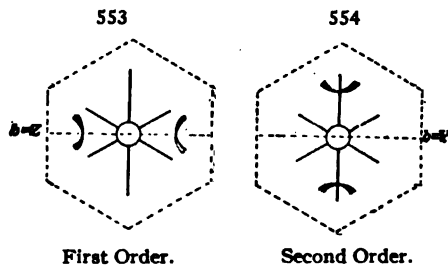
*With crossed nicols.*—Extinction except with *margarite* and unusual *biotite*, which have small extinction angles.

**Basal Sections.**

Often scales or hexagonal plates, always approximately perpendicular to the acute bisectrix X.

*With convergent light* are all biaxial (—). Axial angle varying widely.

*With conical point.*—Percussion figure, p. 215, the most prominent line parallel (010). If the line connecting the axes of the interference figure is at right angles to this the mica is said to be of the first order, Fig. 553, if parallel, of the second order Fig. 554.



The birefringence in the two sections is notably different (see  $\gamma - \alpha$  and  $\gamma - \beta$ ).

|               | Transverse Section. |                 |             | Basal Section.   |         |              |
|---------------|---------------------|-----------------|-------------|------------------|---------|--------------|
|               | $\gamma - \alpha$   | Extinction.     | Pleochroism | $\gamma - \beta$ | Order.  | $2E^\dagger$ |
| Biotite.....  | .033 to .060        | 0° (rarely 10°) | Strong      | 0                | Second* | 0° to 12°    |
| Muscovite.... | .033 to .049        | 0°              | None        | .005 to .008     | First   | 60° to 80°   |
| Paragonite... | Large               | 0°              | None        | Small            | First   | 70 ?°        |
| Phlogopite... | .044                | 0°              | Moderate    | 0                | Second  | 0° to 30°    |
| Margarite...  | .009                | 6° +            | None        | Small            |         | 76° to 120°  |

\* Except anomite.

† Exceptional biotites have  $2E$  60° to 70° and exceptional muscovites have small angles.

**MUSCOVITE. — Potash Mica, White Mica, Isinglass.**

COMPOSITION. —  $H_2(K.Na)Al_3(SiO_4)_3$ , with some replacement by Mg or Fe.

GENERAL DESCRIPTION. — Disseminated six-sided scales and rough crystals, which cleave with great ease into thin, elastic, transparent leaves. Also in masses of coarse or fine scales sometimes grouped in globular, stellate and plumose forms. Usually transparent and pale gray in color, and with pearly lustre on the cleavage surfaces.

CRYSTALLIZATION. — Monoclinic.  $\beta = 89^\circ 54'$ . Prism angle  $= 59^\circ 48'$ . Crystals usually rhombic or hexagonal in section, with rough faces, and usually tapering. Sometimes very large, several feet across. Cleavage is approximately at right angles to the prism.

FIG. 555

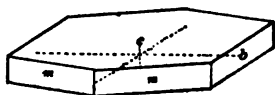
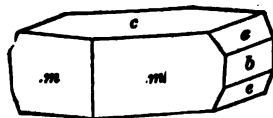


FIG. 556



**Physical Characters.** H., 2 to 2.5. Sp. gr., 2.76 to 3.

LUSTRE, vitreous, pearly on cleavage. TRANSPARENT in laminæ.

STREAK, white.

TENACITY, elastic.

COLOR, gray, brown, green, yellow, violet, red, black.

CLEAVAGE, basal, eminent.

BEFORE BLOWPIPE, ETC.—Fuses only on thin edges to a yellowish glass. Insoluble in acids.

SIMILAR SPECIES.—Differs from talc or gypsum in being elastic. Is *usually* lighter colored than biotite.

**VARIETIES:**

*Fuchsite* is a green muscovite containing chromium.

*Sericite* is secondary muscovite formed in the weathering and alteration of *feldspars* and other silicates as *nephelite*, *scapolite* and *andalusite*. It occurs in fine white scaly or silky aggregates often called talc schist and also often embedded in the cloudy portion of the feldspar. *Damourite*, *margarite*, *pinite*, *gieseckite* are essentially the same material.

REMARKS.—The occurrence, p. 537, and uses p. 481 have been described. The most productive mica mines of the United States are in Mitchell, Yancey, Jackson and Macon Counties, S. C., and Groton, N. H. Other large deposits exist at Grafton, N. H.; Las Vegas and Cribbensville, N. M., and Deadwood and the Black Hills, S.



D., many of which are intermittently mined. Also in Nevada, California, Colorado and Pennsylvania in quantity and quality fit for use. Large quantities of mica are annually imported from India.

**PARAGONITE.**— $\text{H}_2\text{NaAl}_2(\text{SiO}_4)_2$  or sodium muscovite, occurring in massive scaly aggregates similar to sericite but not known as a primary mineral. It constitutes the mass of a rock at Mt. Campione, Switzerland, containing staurolite and cyanite and a soapstone-like mass with actinolite at Pfitschthal and Zillerthal, Tyrol.

### BIOTITE. — Black Mica, Magnesium Mica.

**COMPOSITION.**—An orthosilicate approximating  $(\text{H.K.})_x(\text{Mg.Fe})_z\text{-Al}_x(\text{SiO}_4)_z$ .

**GENERAL DESCRIPTION.**—The most common of the micas. Accompanies muscovite in granitic rocks and schists, but is usually dark green to black in color and in comparatively small scales. Also as black, green and red crystals at Vesuvius. It cleaves into thin, elastic leaves.

**CRYSTALLIZATION.**—Monoclinic.  $\beta = 90^\circ$ .  $a : b : c = 0.577 : 1 : 3.274$ . Habit tabular, Fig. 555. *mm* supplement angle  $60^\circ$ .

**Physical Characters.** H., 2.5 to 3 Sp. gr., 2.7 to 3.1.

**LUSTRE,** pearly, vitreous, submetallic. **TRANSPARENT** to opaque.

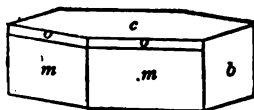
**STREAK,** white.

**TENACITY,** tough and elastic.

**COLOR,** commonly black to green. **CLEAVAGE,** basal, eminent.

**BEFORE BLOWPIPE, ETC.** Whitens and fuses on thin edges. Decomposed by boiling sulphuric acid, with separation of scales of silica.

FIG. 557



**REMARKS.**—Occurs as described on p. 537. It alters much more readily than muscovite, epidote, or hydrous micas. Prominent localities are Vesuvius, Lake Baikal, Greenwood Furnace, N. Y., Pikes Peak, Col., Butte, Mont.

### PHLOGOPITE. — Amber Mica, Bronze Mica.

**COMPOSITION.**— $\text{R}_3\text{Mg}_3\text{Al}(\text{SiO}_4)_3$ , where  $\text{R} = \text{H, K, MgF}$ .

**GENERAL DESCRIPTION.**—Large and small, brownish-red to nearly black crystals. Usually rough, tapering, six-sided prisms. Thin plates sometimes show a six-rayed star by transmitted light.

**Optically.**— Axial plane parallel to *b*, that is *parallel* to the principal line of the percussion figure. Axial angle small, but varying in the same specimen. Pleochroic in colored varieties.

**Physical Characters.** H., 2.5 to 3. Sp. gr., 2.78 to 2.85.

LUSTRE, pearly or submetallic. TRANSPARENT to translucent.

STREAK, white. TENACITY, tough and elastic.

COLOR, yellowish-brown, brownish-red, green, colorless.

CLEAVAGE, basal eminent.

**BEFORE BLOWPIPE, ETC.**—Whitens and fuses on thin edges. In closed tube yields water. Soluble in sulphuric acid with separation of scales of silica.

**REMARKS.**—Occurs in enormous crystals in Ontario and Quebec, and in various localities through New York and New Jersey.

#### MARGARITE.

**COMPOSITION.**— $H_2CaAl_4Si_2O_{12}$  = Silica 30.2, alumina 51.3, lime 14.0, water 4.5 = 100.

**GENERAL DESCRIPTION.**—Gray to pink micaceous material with pearly lustre, incrusting corundum or associated with it. H., 3.5 to 4.5. Sp. gr., 2.99 to 3.08.

**BEFORE BLOWPIPE, ETC.**—Whitens and fuses at 4.5. Yields water in closed tube. Slowly decomposed in hydrochloric acid.

**REMARKS.**—Found in this country with corundum at Chester, Mass.; Unionville, Pa.; Crugers Point, N. Y.; Gainesville, Ga.; Dudleyville, Ala. Foreign occurrences are Naxos and Gumuch-Dagh, Asia Minor; Sterzing, Tyrol, etc.

#### THE CHLORITE GROUP.

The species described are:

|             |                                 |                      |
|-------------|---------------------------------|----------------------|
| Clinocllore | } $H_2(Mg, Fe)_2Al_2Si_2O_{10}$ | Monoclinic           |
| Penninite   |                                 |                      |
| Prochlorite |                                 | Monoclinic <i>g/</i> |

Species or doubtful species elsewhere described are *chamosite*, *thuringite* and *berthierine*, p. 276.

Many other names have been given, the chlorites being probably isomorphous mixtures of undetermined end members.

Tschermak assumed an isomorphous series analogous to the plagioclase series with serpentine (Sp),  $H_4(Mg, Fe)_2Si_2O_6$ , at one end and a chlorite from Chester, Mass., Amesite (At),  $H_4(Mg, Fe)_2Al_2Si_2O_6$ , as the other. On this theory the distinctly crystallized species clinocllore and penninite are SpAt, the species prochlorite is  $Sp_2At_{17}$  and the species corundophilite  $SpAt_4$ .

A number of dark green chlorite-like substances occurring in fine scales and fibres and not distinguishable from one another microscopically are given names on the basis of analyses but are in general simply described as *chlorites* or *leptochlorites*. Delessite is a type.

## FORMATION AND OCCURRENCE OF CHLORITES.

**In Igneous Rocks.**

They are never primary in igneous rock but very common as secondary minerals not only as the green unidentified pigment called *viridite* but as irregular scaly aggregates and pseudomorphs formed from biotite, amphibole, pyroxene, garnet, or less directly from feldspars and ferromagnesian minerals combined.

**In Metamorphic Rocks.**

Very widely distributed and very difficult usually to distinguish from one another. Sometimes dominant forming chlorite schists, or in other schists, sometimes forming veins in serpentine, often with magnetite.

## OPTICAL DETERMINATION OF CHLORITES.

The microscopic varieties are optically indistinguishable, the coarse may in part be distinguished from each other.

**Characters in Common.***In transverse section.*

*Color* usually green, occasionally red (Cr).

*Relief* slight in balsam.  $\gamma = 1.57$  to  $1.59$ .

*Pleochroism* marked in greens and yellows.

*In basal section.*

*Pleochroism* not observable.

*Interference colors* none or faint.

**Differential Characters.**

|                  | Extinction<br>with Cleav-<br>age. $Z$ to $c$ | Axial<br>Angle<br>$2E$   | Interference Colors<br>(Transverse Section)<br>$\gamma - a$ . | Interference<br>Figure. |
|------------------|--|--------------------------|---|-------------------------|
| Clinochlore..... | $2^\circ$ to $7^\circ$                       | $12^\circ$ to $90^\circ$ | .01 like quartz   | Biaxial (+)             |
| Penninite.....   | $0^\circ$                                    | $0^\circ +$              | .001 to .003 nearly black or<br><i>anomalous indigo blue</i>  | Uniaxial ( $\pm$ )      |
| Prochlorite..... | $0^\circ +$                                  | $0^\circ$ to $30^\circ$  |   | Biaxial (+)             |

**CLINOCHLORE.**

COMPOSITION.— $H_2(Mg.Fe)_2Al_2Si_2O_{12}$ .

GENERAL DESCRIPTION.—Green, white and rose-red crystals with cleavage like mica, the cleavage plates however being only slightly elastic. Also masses made up of coarse or fine scales and earthy. H., 2 to 2.5. Sp. gr., 2.65 to 2.78.

CRYSTALLIZATION.—Monoclinic. Pseudo-hexagonal. Crystals usually six-sided plates, or sometimes with rhombohedral habit.

**BEFORE BLOWPIPE, ETC.**—Whitens and fuses with difficulty to a grayish black glass. In closed tube yields water at a high heat. Soluble in sulphuric acid, only slightly so in hydrochloric acid.

**REMARKS.**—Found in green chlorite schist at Achmatowak, Urals, and Zillerthal, Tyrol. In serpentine at Westchester, Penn. Rose red (*kotschubeite*) in California and Urals. White (*leuchtenbergite*) in Traversella, etc.

#### PENNINITE.

**COMPOSITION.**—Like clinocllore.

**GENERAL DESCRIPTION.**—Like clinocllore but crystals thick pseudorhombodehral or tapering.

**BEFORE BLOWPIPE.**—Like clinocllore.

**REMARKS.**—The differences are chiefly optical (see p. 542) and in habit of crystals. Found in Zermatt, Switzerland; Zillerthal, Tyrol; Ala, Piedmont; Texas, Penn., as cherry red *kämmererite*.

#### PROCHLORITE.

**COMPOSITION.**— $H_{40}(Fe,Mg)_2Al_4Si_{12}O_{60}$ .

**GENERAL DESCRIPTION.**—Dark-green masses, composed of coarse to very fine scales. Also tabular and sometimes twisted six-sided crystals, which easily cleave into thin plates which are not elastic. H., 1 to 2. Sp. gr., 2.78 to 2.96.

**BEFORE BLOWPIPE, ETC.**—Whitens and fuses to a nearly black glass. In closed tube yields water. Soluble in sulphuric acid.

**REMARKS.**—Found massive in Montgomery Co., N. C., and in the tin veins of Cornwall. Other localities are St. Gothard on adularia; Traversella, Piedmont; Zillerthal, Tyrol; Washington, D. C.

**DELESSITE**, a dark-green massive mineral of scaly or short fibrous appearance. H., 2.5. Sp. gr., 2.9. It yields water in the closed tube and is decomposed by HCl with separation of silica. Found in cavities of amygdaloidal eruptive rocks.

### THE HYDROUS SILICATES OF MAGNESIUM.

The species described are:

|            |                     |            |
|------------|---------------------|------------|
| Serpentine | $H_4Mg_3Si_2O_9$    |            |
| Talc       | $H_2Mg_3(SiO_3)_4$  | Monoclinic |
| Sepiolite  | $H_4Mg_5Si_8O_{16}$ |            |

#### FORMATION AND OCCURRENCE.

Both are secondary minerals chiefly formed, it is believed, by the alteration (possibly by carbonated water) of magnesian silicates such as *chrysolite*, *enstatite*, *hypersthene*, *anthophyllite* and *tremolite*, but also by the action of magnesian waters on non magnesian silicates such as feldspar.

#### Secondary in Igneous Rocks.

*Serpentine* forms as a rock from peridotite, according to Weinschenck,\* other rocks such as pyroxenite "never turn to serpentine."

\* "Petrographic Methods," 315 (Weinschenck-Clark).

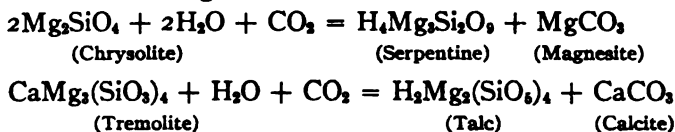
*Serpentine* forms as pseudomorphs in rocks containing chrysolite, etc., sometimes after the parent mineral, sometimes after a mineral which it has displaced.

*Talc* may form as a rock from peridotite.\* *Soapstone* is probably altered eruptive rock.

### In Metamorphic Rocks.

*Serpentine* in layers between gneiss, granulite, limestone, talc and chlorite schist.

*Talc* is common in chloritic schists, serpentine, dolomite, etc. The talc beds of St. Lawrence Co., N. Y., are regarded as secondary alterations of tremolite or enstatite in schistose limestone. For instance Clarke gives†



### THE OPTICAL DETERMINATION.

Serpentine and talc in thin sections are essentially colorless, non-pleochroic and with little relief ( $\gamma$  1.51 to 1.59). Both are biaxial and the lammellae of antigorite and talc may show interference figures respectively (+) and (-). The elongation of chrysotile fibres is (+). Antigorite laths show as "lattice structure," chrysotile fibres as "net or mesh structure." The minerals differ optically chiefly in birefringence.  $\gamma - \alpha$  in *serpentine* is .011 to .013, giving colors in thin sections in middle and end of first order. In talc  $\gamma - \alpha$  is .038 to .043, giving bright third order colors like *muscovite*. Indeed *sericite* (muscovite) and talc are not distinguishable by optical tests.

### SERPENTINE.

COMPOSITION.— $\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$ , with replacement by Fe.

GENERAL DESCRIPTION.—Fine granular masses or microscopically fibrous. Also foliated and coarse or fine fibrous. Color, green, yellow or black, and usually of several tints dotted, striped and clouded. Very feeble, somewhat greasy lustre and greasy feel. Crystals unknown.

\* *Ibid.*, 317, by "intense chemical processes" sometimes near acid eruptives.

† Bull. U. S. Geol. Surv. 491, p. 575 and 578.

**Physical Characters.** H., 2.5 to 4, Sp. gr., 2.5 to 2.65.

LUSTRE, greasy, waxy or silky. TRANSLUCENT to opaque.

STREAK, white. TENACITY, brittle.

COLOR, green to yellow, brown, red, black, variegated.

BEFORE BLOWPIPE, ETC.—Fuses on edges. In closed tube, yields water. In cobalt solution becomes pink. Soluble in hydrochloric acid, with a residue.

**VARIETIES:**

*Serpentine Rock*.—Containing the three varieties below with unaltered *chrysolite*, *pyroxene*, etc., and by-products *chromite*, *magnetite*, *magnesite*, sometimes *garnierite*.

*Antigorite*.—Lamellar or flaky deep green material or lath-like crystals in seams and crevices of serpentine rock.

*Chrysotile*.—Seams and crevices in the chrysolite fill with fibres perpendicular to their sides and later the compact serpentine fills in between.

*Massive or Compact Serpentine*.—Dense aggregates making up the ground mass of most occurrences.

**REMARKS.**—Chrysotile in commercial quantities occurs in Vermont and Arizona; the great source however is the Thetford region, Quebec, Canada. Massive serpentine or verd antique marble is obtained at Milford, Conn. Many localities such as Newburyport, Mass.; Montville, N. J.; Texas, and West Chester, Penn., yield serpentine of ornamental quality. Well-known foreign localities are Falun, Sweden; Portlsey, Aberdeen; the Lizard Cornwall, New Zealand (Bowenite).

**TALC.—Steatite, Soapstone.**

**COMPOSITION.**— $H_2Mg_3(SiO_3)_4$ .

**GENERAL DESCRIPTION.**—A soft, soapy material, occurring foliated, massive, and fibrous, with somewhat varying hardness. Usually white, greenish or gray in color. Crystals almost unknown.

**Physical Characters.** H., 1 to 4. Sp. gr., 2.55 to 2.87.

LUSTRE, pearly or wax-like. TRANSLUCENT.

STREAK, white. TENACITY, sectile.

COLOR, white, greenish, gray, brown, red.

CLEAVAGE, into non-elastic plates. FEEL, greasy.

**BEFORE BLOWPIPE, ETC.**—Splits and fuses on thin edges to white enamel. With cobalt solution, becomes pale pink. Insoluble in acid.

**VARIETIES.**

*Foliated Talc.*— $H = 1$ . White or green in color. Cleavable into non-elastic plates.

*Soapstone or Steatite.*—Coarse or fine, gray to green, granular masses.  $H$ , 1.5 to 2.5.

*French Chalk.*—Soft, compact masses, which will mark cloth.

*Agolite.*—Fibrous masses of  $H$ . 3 to 4.

*Rensselaerite.*—Wax-like masses.  $H$ , 3 to 4. Pseudomorphous after pyroxene.

**SIMILAR SPECIES.**—Softer than micas or brucite or gypsum. Further differentiated by greater infusibility, greasy feel, and the flesh-color obtained with cobalt solution.

**REMARKS.**—Much of the so-called talc schist has proved to be sericite (or secondary muscovite) in scaly aggregates harder than talc but undistinguishable optically. An immense deposit of fibrous talc at Gouverneur and Edwards, N. Y., is mined, and the total output is ground for use in paper-making, etc. Large soapstone quarries are worked at Frankestown, N. H., Chester, Saxon's River, Cambridgeport and Perkinsville, Vt., Cooptown, Md., and Webster, N. C. Massachusetts, New Jersey, Pennsylvania, Virginia and Georgia are also producing states.

**SEPIOLITE.—Meerschaum.**

**COMPOSITION.**— $H_4Mg_2Si_2O_{10}$ .

**GENERAL DESCRIPTION.**—Soft compact white, earthy to clay-like masses, of very light weight. Rarely fibrous.

**Physical Characters.**  $H$ , 2 to 2.5. Sp. gr., 1 to 2.

LUSTRE, dull.

OPAQUE.

STREAK, white.

TENACITY, brittle.

COLOR, white, gray, rarely bluish-green.

FEEL, smooth.

**BEFORE BLOWPIPE, ETC.**—Blackens, yields odor of burning and fuses on thin edges. In closed tube yields water. With cobalt solution becomes pink. In hydrochloric acid gelatinizes.

**SIMILAR SPECIES.**—Resembles chalk, kaolinite, etc., but is characterized by lightness and gelatinization with acids.

**REMARKS.**—Possibly formed from Magnesite. The name "meerschaum" refers to the fact that it will float on water when dry. Most of the material used for pipes is

obtained from Turkey. It occurs in large amount in Spain, and in smaller quantities in Greece, Morocco and Moravia. There are no productive American localities.

USES.—As material for costly tobacco pipes. In Spain it is a building stone. In Algeria it is used as a soap.

### THE HYDROUS SILICATES OF ALUMINUM.

The species described are:

|                      |                   |                            |
|----------------------|-------------------|----------------------------|
| Well characterized   | { Kaolinite       | $H_4Al_2Si_2O_9$           |
|                      | { Pyrophyllite    | $HA1(SiO_3)_2$             |
|                      | { Halloysite      | $H_4Al_2Si_2O_9 + H_2O$    |
| Poorly characterized | { Allophane       | $Al_2SiO_5 + 5H_2O$        |
|                      | { Montmorillonite | $H_2Al_2(SiO_3)_4 + nH_2O$ |

### FORMATION AND OCCURRENCE.

#### Residual and Sedimentary Clays.

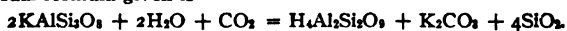
The great aluminum silicates, especially the feldspars, nephelite, and wernerite, by weathering, tend to form hydrous silicates of aluminum as residual products. These consist in part probably of the definite silicate kaolinite\* chemically equivalent to serpentine but largely of colloidal residues, "gels," less definitely recognizable and hardly to be called true minerals. The deposits known as CLAYS contain also free quartz and varying amounts of many other species. The clays may be "residual" resulting from decay in place as with the china clays of Meissen, Saxony, and Cornwall, England, or they may have been transported by water, ice or wind and redeposited as "sedimentary" clays. The original rocks from which they formed may be of almost any class, granites syenites, pegmatites and even basic rocks; gneiss, limestones, shales. Plasticity in clays appears to be dependent on the colloidal matter present whether silicic acid, alumina, iron oxide or organic.†

#### KAOLINITE.—Kaolin, China Clay.

COMPOSITION.— $H_4Al_2Si_2O_9$ .

GENERAL DESCRIPTION.—Compact and clay-like or loose and mealy masses of pure white, or tinted by impurities composed of

\* The usual formula given is



Orthoclase

Kaolinite

† See N. B. Davis, *Trans. Am. Inst. Min. Engs.*, Feb., 1915.



extremely minute scales and plates. Rarely crystallized in small rhombic or six-sided plates optically monoclinic.

**Physical Characters.** H., 2 to 2.5. Sp. gr., 2.6 to 2.63.

LUSTRE, dull or pearly.

OPAQUE or translucent.

STREAK, white or yellowish.

TENACITY, brittle.

COLOR, white, yellow, brown, red and blue.

It is stated that the cloudy effects in feldspars are due to sericite and not kaolin which is rarely observed in thin sections.\* Kaolinite should show no relief (index 1.55) in balsam and low interference colors ( $\gamma - \alpha = .007$ ).

**BEFORE BLOWPIPE, ETC.**—Infusible. Yields water in closed tube. With cobalt solution, becomes deep blue. Decomposed by sulphuric acid, but is insoluble in nitric or hydrochloric acids.

**REMARKS.**—*Kaolinite* in crystalline scales occurs at the National Bell Mine, Silverton, Col., and at Tamaqua, Penn. Kaolinite is mined at Okahuimka, Lake County, Florida, at Sylva, Dillsboro and Webster, N. C., and at several places in New Castle County, Del., and Chester and Delaware Counties, Pa. Kaolin of poorer quality is obtained in Ohio and New Jersey, and many other deposits are known throughout the Atlantic States.

FIG. 558.



Pyrophyllite, Lincoln Co., Ga. N. Y. State Museum.

**PYROPHYLLITE.—Pencil Stone.**

**COMPOSITION.**— $\text{HAl}(\text{SiO}_3)_2$ .

**GENERAL DESCRIPTION.**—Radiated foliæ or fibres and compact masses of soapy feeling and soft and smooth like talc.

\* Weinschenck-Clark, "Petrographic Methods," p. 318.

white, greenish, brownish or yellow. Streak, white. H., 1 to 2. Sp. gr., 2.8 to 2.9. Flexible.

**BEFORE BLOWPIPE, ETC.**—Whitens and fuses on the edges, and often swells and spreads like a fan. In closed tube yields water. Partially soluble in sulphuric acid.

**REMARKS.**—Occurs in beds with schists as compact material at Deep River, N. C. and as foliated material, often radiated, in Lincoln Co., Ga.; Ouro Preto, Brazil. Often with cyanite.

**USES.**—Extensively manufactured into slate pencils, foot warmers and other uses of "soapstone."

**HALLOYSITE.**—Probably  $H_4Al_2Si_2O_9 + H_2O$  (Le Chatelier). Amorphous clay-like white or yellowish material. H., 1 to 2. Sp. gr., 2.0 to 2.2.

**BEFORE BLOWPIPE, ETC.**—As for kaolinite but yielding more water in closed tube.

**REMARKS.**—Includes *indianait*, a compact china clay, of Lawrence Co., Indiana, and is considered to be the principal constituent of many clay beds in Alabama, Georgia; Steinbruck, Styria; Elgin, Scotland, and elsewhere.

**ALLOPHANE.**— $Al_2SiO_5 + 5H_2O$ .

A translucent, sometimes wax-like material often found in copper and iron mines, filling crevices and fissures or stalactitic and colored by intermixtures of chrysocolla, malachite or limonite; also in cavities in marls and limestones. H., 3. Sp. gr., 1.85 to 1.89.

**BEFORE BLOWPIPE, ETC.**—Crumbles but is infusible. Becomes blue color with cobalt solution. Gelatinizes with hydrochloric acid.

**REMARKS.**—Occurs at Richmond, Mass., with gibbsite. In marl at Saalfeld, Thuringia. With copper minerals in Polk Co., Tenn.

**MONTMORILLONITE.**—Probably  $H_2Al_2Si_4O_{13} + n$  aq.

Very soft, often soap-like, white, pinkish or variously colored material, which softens in water and does not adhere to the tongue. H., 1 ? Sp. gr., 2 to 2.2.

**BEFORE BLOWPIPE, ETC.**—Infusible, loses water.

**REMARKS.**—Found at Branchville, Conn. (pink); Montmorillon, France (rose red) and many clay-like materials of similar properties are grouped under it as a type, such as *stolpenite*, *saponite*, *erinite*, *severite*, *confolensite*, etc.

## CHAPTER XXI.

### MINERALS USED AS PRECIOUS AND ORNAMENTAL STONES.

No very systematic order is followed; the species are described in two groups:

A. The Transparent Stones.

B. The Translucent to Opaque Stones.

Where the species has been described already the description is not duplicated but the properties\* which count most in the durability and beauty of the stone are assembled and detailed, and with these characters something is given as to occurrence. Very little is stated as to the history, methods of cutting, famous stones, superstitions, etc., the descriptions in fact being of the native uncut mineral, not of the cut stone.

#### A. THE TRANSPARENT STONES.

##### DIAMOND.

COMPOSITION.—C.

GENERAL DESCRIPTION.—Transparent, isometric crystals with a peculiar adamantine lustre like oiled glass. Usually colorless or slightly tinted. Also translucent, rough, rounded aggregates and opaque or compact masses of gray to black color. Especially characterized by a hardness exceeding that of any other known substance.

CRYSTALLIZATION. — Isometric. Crystals practically always complete, showing no signs that they were ever attached to any support. Usually in octahedrons, Fig. 560, with smooth faces or with triangular markings, often with edges replaced by smaller faces,\* Fig. 559, which frequently results in a rounded many-faced

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\* For instance the DURABILITY is dependent on hardness, density, toughness and absence of too easy cleavages; the beauty upon agreeable color, clearness or transparency, brilliancy or lustre (itself dependent both on density and index of refraction) and fire (itself dependent on dispersion).

\* Hextetrahedral modifying faces are most common, while rounded hexoctahedra and, more rarely, cubes and other forms occur. Frequently twinned parallel to the octahedron.

crystal. Very perfect cleavage parallel to the octahedron, that is, in four directions at angles of  $70^{\circ} 31'$  and  $109^{\circ} 28'$  to each other. Readily developed by a sharp blow on a knife held in proper position, this being usually preceded by a scratch.

FIG. 559.



FIG. 560.

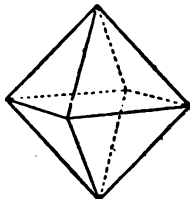


FIG. 561.



### Physical Characters.

**HARDNESS.**—It is called 10, but the stones from Borneo and N. S. Wales are much harder than those from other localities and the Cape stones are softer. The hardness may vary in parts of the same stone.

**SPECIFIC GRAVITY.**—3.145 to 3.518 (Crookes.) Bort and Carbonado range 3.47 to 3.50.

**LUSTRE.**—When polished peculiarly brilliant, typical adamantine. When unpolished like oiled glass.

**COLOR.**—Colorless or faintly bluish or less valued "off-colors" tinged with yellow, brown and green. More rarely decided colors—red, pink, sapphire blue (a little greenish), canary yellow, decided green.

### Optical Characters.

**REFRACTION.**—Single with index very high and constant. 2.4175. Often local double refraction, due to strain (sometimes from included liquid carbonic acid).

**TOTAL REFLECTION.**—Critical angle very small  $24^{\circ} 26'$ , this permitting the stone to be cut so as to send back all entering light.

**COLOR DISPERSION.**—Very high, .044, exceeded only by titanite, .051, and demantoid, .057. Approached by zircon, .038.

**ABSORPTION SPECTRUM.**—Not constant, sometimes a line in the violet.

**PERMEABILITY TO X-RAYS.**—Highly transparent.

**LUMINESCENCE.**—Excited in some diamonds by ultra-violet light or by radium or X-rays as a clear, luminous blue, a few

become luminous on mere rubbing and others by exposure to sunlight.

**BEFORE BLOWPIPE, ETC.**—In fine powder is slowly burned in presence of air over a bunsen burner or alcohol lamp. In large mass and in absence of air is very little affected even by white heat. Insoluble in acids.

**VARIETIES:**

*Ordinary.*—In rounded crystals with distinct cleavage.

*Bort.*—Technically any diamond or fragment of diamond not deemed worthy to be cut. Crystallographically, an individual composed of many smaller crystals, sometimes enclosing a simple crystal, oftener not, and having no constant directions of cleavage. Sometimes the little crystals are radially placed and their edges form a rough surfaced sphere.

*Carbonado.*—Black massive or granular material from Brazil.

**Formation and Occurrence.**

The only chance of studying the genesis of the diamond in place is in South Africa. In this region the diamond-bearing ground consists of comparatively limited areas circular or oval in form, the upper portion pale yellow and crumbly, but lower down firmer and bluish-green. The diamonds are distributed through the mass sometimes 4 to 6 to the cubic yard.

The minerals with the diamonds are chiefly broken fragments of serpentine, diallage, garnet, magnetite, etc., and the mass extends downward nearly vertically but narrowing somewhat like large "*pipes*" or cylinders or funnels for an unknown depth.

The older theory was that these funnel-shaped pipes were volcanic like Vesuvius and that the diamonds were formed with considerable heat. There are various objections. Volcanoes would have formed elevations and there would have been overflows. No indications of this exist and even if present conditions resulted from erosion there would have been as a result of the erosion diamonds and rocks from the pipes in the ravines and water courses in the vicinity, but there never are, the nearest being 20 miles distant. Moreover, the diamonds have retained their form and brilliancy, whereas Herr W. Ludzi, of Leipzig, fused in a crucible at about 2,000° centigrade the "blue ground" containing

diamonds and half an hour of this resulted in a marked corrosion of the crystals.

A theory which seems to have greater probability is that the blue ground was forced up from below under great pressure by steam and other vapors. The diamonds show signs of this great pressure, often containing liquid drops of carbonic acid, and the blue ground being heterogeneous mixed-up or broken material, apparently originally a rock of such material as pyroxene and garnet, some of which is often included boulder-like in the mass. The sides of the contact wall also show smoothed surfaces (slickensides) and scratches, suggesting the up-and-down motion several times of this material. Such a theory would also explain the absence of the rock in the ravine nearby, because the pasty mass of mud by the escape of the vapors would settle down rather than protrude and would be protected from erosion.

#### **The Cutting of Diamonds.**

Until the fifteenth century diamonds were not cut but worn in the natural state or covered with a green varnish. Some little polishing of the natural faces had been done by native lapidaries and to disguise the presence of little flaws or defects.

In 1475 Louis de Berquem discovered that, by rubbing one stone with another, diamonds could be cut and is said to have cut three large stones for Charles the Bold of Burgundy.

Wheels charged with diamond dust followed but as late as 1562 the only forms were the octahedron and the table, in the latter of which one solid angle of the octahedron had been cut off until the resulting new face was one half the width of the stone.

These were followed by the rose cut with a flat base and 24 triangular facets, and the brilliant,\* Fig. 561, a modification of the table with more faces, usually 58, 33 above the girdle, 25 below. Its angles are chosen so that the incident light entering falls on the lower faces at angles *greater* than the critical angle,  $24^{\circ} 26'$ , and is totally reflected, preferably through the inclined faces, thus producing extreme brilliancy and dispersion of the light or color.

#### **Artificial or Synthetic Diamonds.**

Diamonds were found by Friedel in the Cañon Diablo meteorite. Moissan thereupon experimented by saturating iron with carbon,

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\* Said to have been discovered by Vincenzo Peruzzi in 1790.

then fusing the mass and pouring quickly into a vessel containing water and mercury. Minute crystals barely visible to the naked eye were obtained.

Majorana heated carbon in the electric arc and while hot blew it by an explosion of gunpowder into a cavity in a steel block. Small diamonds resulted. Pulverized carbon heated on iron wire in the electric arc in an atmosphere of hydrogen yielded diamond crystals.

Silicates like the blue ground fused in a crucible with carbon yielded small diamonds.

REMARKS.—Diamonds have been known in India for over 3,000 years but do not appear to have reached Europe until about the time of Caesar Augustus. They were not valued for their beauty but for supposed supernatural virtues and worn uncut and unpolished and indeed until the fifteenth century had at most their natural faces polished.

India supplied practically all the diamonds until 1725, when the Brazilian deposits were discovered and Brazil in turn supplied the world until 1867, when the River diggings of South Africa and a little later, 1870, the "dry diggings" or Kimberley deposits were discovered. These still are the great source, although diamonds are or have been obtained from New South Wales, Australia, Rhodesia and German South Africa. A few diamonds have been found in British Guiana, in the Shantung Province, China, and in the gold washings in the Ural Mountains, and in four districts in the United States, first along the western base of the Sierra Nevadas; second, along the line of the Terminal Moraine in Wisconsin, Michigan, Indiana, and Ohio, presumably coming from somewhere in Canada; third, in Kentucky and Tennessee; fourth, along the eastern base of the Appalachians from Virginia to Alabama.

**CORUNDUM.**—Sapphire, Ruby. Described on p. 412.

COMPOSITION.— $\text{Al}_2\text{O}_3$ . Transparent varieties of corundum are known as rubies\* if red, sapphires† if blue and fancy‡ sapphires if other colors, the colorless variety is called white sapphire. The preferred colors are pigeon blood or purplish red and velvety corn flower blue.

#### Optical Characters.

UNIAXIAL (—)  $\gamma$  1.766 to 1.744,  $\alpha$  1.757 to 1.765,  $\gamma - \alpha$  very constant .0083 to .009. Color dispersion weak .018. Pleochroism

\* Ruby is from Latin *rubere* = red.

† The sapphire of the ancients was lapis lazuli, but in course of time this became a general designation of blue stone and later of the blue corundum. Plato's adamant was supposed to have been sapphire. Hyacinth was also used for stone apparently sapphire.

‡ Fancy sapphires are sometimes known as "oriental" topaz, amethyst, etc.

usually distinct, sometimes strong. Twin colors varying with color and locality.

**LUMINESCENCE.**—Very varied. Burmese rubies brilliant red with ultra-violet light, Siam rubies no luminescence. Synthetic rubies more brilliant even than Burmese. Ceylon rubies phosphorescent (yellow) on heating.

**EFFECTS OF HEAT.**—Ruby loses color but cools through white and green to the original tint. Sapphire strongly heated is decolorized in part and if pale violet or yellow may become white, if deep violet may become rose colored.

FIG. 562.



Corundum Crystals, Ceylon. U. S. National Museum.

**BEAD TESTS.**—Synthetic and natural rubies color salt of phosphorus beads green in R. F.

**OCCURRENCE.**—Very largely from gravels or alluvial deposits sometimes in place as in Yogo Gulch, Montana, and Siam.

**SAPPHIRES.**—*Ceylon.*—Chiefly from the gravels in Sabara Gamuwa province with spinel, zircon, beryl, topaz, etc. These gravels extend far below water level, and in one case 120 ft. and underlie swamps and rice fields. The crystals are pyramidal (while the corundum in place is prismatic).

*Siam.*—Probably half the sapphires, including the finest corn flower blue stones are from Siam.

*India.*—In Kashmir in the Himalayas, 14,000 ft. above sea level, fair quality stones occur in a hard rock (gneiss) and were found in considerable quantities at the foot of a precipice where a landslide had occurred.



*Australia.*—Many colors, but none red or fine blue, are found near Anakie, Queensland, in a gravel of decomposed basalt.

*Montana.*—At Yogo Gulch in place in a dike which cuts through limestone and in gravels on the Upper Missouri River. The colors are given as deep and light aquamarine, greens, yellows, pinks, amethystine. The lustre is peculiar, almost metallic.

**RUBIES.**—*Burmah.*—The most valued rubies come from Mogok north of Mandalay in Upper Burmah, 4,000 ft. above sea.

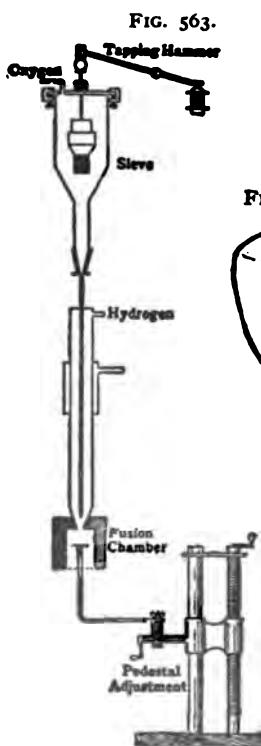
They occur in a sort of clay called "byon," considered to be the result of the decay of a crystalline limestone containing also spinels, sapphires, and tourmalines. Also found in a gravel bed underlying alluvial deposits in Mogok Valley.

*Siam.*—Darker colored rubies are found in Siam associated with red spinel and sapphires at the Navony Mine near Bangkok. Some also are found with the sapphires at the Pailinh Sapphire Mine in eastern Siam.

*Ceylon.*—Not found in place and only comparatively rarely in the gravels. They are never the true Burmese red, though often more brilliant.

### Synthetic Rubies and Sapphires.

Corundum is synthetically made by the method of Verneuil in



pear-shaped drops or "boules,"

Fig. 564, which are true anhedral crystals, and are character for character, except shape, identical with the natural ruby or sapphire.\* They bear the same relation to the natural stone that the ice of the pond does to the manufactured ice and while easily distinguished before cutting, are distinguished afterwards only with difficulty by inclusions, mode of distribution of color, etc. The apparatus of Veneuil, Fig. 563, is an inverted oxyhydrogen blowpipe, in which the raw material, a carefully prepared powder, is sifted regularly through a sieve into an enlargement of the oxygen tube, the speed being regulated by a tapping hammer, and is carried with the oxygen

\* A. J. Moses, *Amer. Jour. Sci.*, XXX, 271, 1910.

to the fusion chamber and falls as a melted drop on the support, where it gradually builds up the boule.

#### STONES RESEMBLING THE SAPPHIRE.

**IOLITE.**—Water sapphire. Described on p. 529. The stones that are usually cut are light to dark smoky blue. It also occurs violet.

*Pleochroism* very strong. The principal colors—smoky blue and yellowish white—being visible to the unaided eye. It is therefore cut with the table face perpendicular to the direction of deepest blue.

*Occurrence Cutting Material.*—Chiefly found in water-worn masses in the river gravels of Ceylon. One piece in the British Museum weighs 177 grams. The Had-dam, Conn., material is sometimes cut. Other localities are Bodenmais, Bavaria, Finland, Sweden.

**BENITOITE.**— $\text{BaTi}(\text{SiO}_3)_2$ . This stone was discovered in 1906 and at first cut and sold as sapphire. Few stones exceed 2 carats, one was 7 carats. The characters of importance are as follows: H., 6.5. Sp. gr., 3.64 to 3.72.

*Color.*—Varies from deep blue with a violet tint to pure blue or a lighter shade, sometimes perfectly colorless.

*Refraction and Indices of Refraction.*—Doubly refracting, uniaxial, positive. Ordinary index is 1.757 and the extraordinary 1.804.

*Birefringence* strong, .047 (Eppler says .03).

*Dispersion* strong, producing considerable fire.

*Pleochroism* strong, ordinary ray white—extraordinary greenish blue to reddish blue. As light transmitted perpendicularly to the base is practically colorless, the gem should be cut with a table parallel to the principal axis which is contrary to the rule for sapphire.

*Effects of Heat.*—Color unchanged until it fuses quietly to a transparent glass at about 3. Salt of phosphorus bead violet in reducing flame.

*Effects of Acid.*—Practically insoluble in hydrochloric acid, readily attacked by hydrofluoric acid and dissolves in fused sodium carbonate.

*Occurrence.*—Occurs in veins and crusts of natrolite in a hornblende schist of the Coast Range of California. It occurs with the rare mineral neptunite, in Diablo Range, near the headwaters of San Benito River, California.

**CYANITE.**—*Composition.*— $\text{Al}_2\text{SiO}_5$ . Described on p. 519.

Azure to cornflower blue varieties only are cut. Green and white occur.

There are many distinctions from sapphire such as hardness, 5 to 7, numerous striations and cracks, lower indices,  $\gamma$  1.728  $\alpha$  1.712, lower specific gravity, 3.56 to 3.67.

*Occurrence of Cutting Material.*—The finest sky blue crystals come from Mt. Campione, St. Gothard, Switzerland; Zillerthal and Pfitschthal, Tyrol; India (where it is sorted with sapphire and sold at good prices), near the peak of Yellow Mt., Bakersville, N. C., and Diamantina, Brazil.

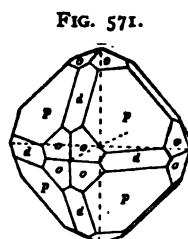
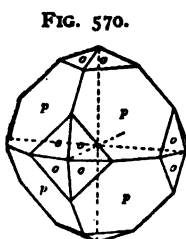
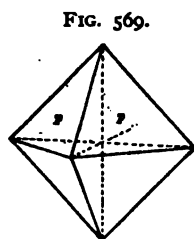
**HAÜYNITE.** *Composition.*— $\text{CaSO}_4 \cdot 2(\text{Na}_2\text{Ca})\text{Al}_2(\text{SiO}_4)_2$ . Described on p. 500.

Occurs occasionally as transparent sky-blue grains, and is cut. Its isotropic character and very low index, 1.49, distinguish it.

*Occurrences Cutting Material.*—Near Albano, Italy, in Auvergne, France, and at Niedermendig on the Rhine.

**SPINEL.\*—Balas Ruby.**

**COMPOSITION.**— $\text{Mg}(\text{AlO}_2)_2$ , (MgO 28.2,  $\text{Al}_2\text{O}_3$  71.8 per cent.). Iron, manganese and chromium are sometimes present.



**GENERAL DESCRIPTION.**—Usually in octahedral, simple or twinned crystals, varying in color according to composition, and even in the gravels which round the still harder ruby retaining much of their sharpness.

Spinel is not well known as a gem partly because the red varieties were until comparatively recently not distinguished by jewelers from the ruby. Some great historic rubies have proved to be spinels.

**CRYSTALLIZATION.**—Isometric, the octahedron *p* or this modified by the dodecahedron *d* or the trapezohedron *o* = (*a* : 3*a* : 3*a*); {311}.

**VARIETIES:**

The transparent varieties most valued are:

*Balas Ruby.* Rose red or pink. *Ruby Spinel.* Clear red.

These varieties are said always to show a pale yellow reflection from the interior of the stone.

Less valued are: *Rubicelle*, yellow to orange; *Sapphirine*, steely blue; *Almandine*, purple to violet.

The opaque varieties include: *Ceylonite* (Iron Magnesia Spinel).—Dark-green, brown, black, usually opaque. *Picotite* (Chrome Spinel).—Yellowish to greenish-brown, translucent.

**Physical Characters.** H., 8 to 8.5. Sp. gr., 3.5 to 3.7. (Ceylonite 4.1.)

LUSTRE, vitreous.

COLOR, as given and intermediate.

STREAK, white.

CLEAVAGE, octahedral difficult.

\* From a word for a "little spark," referring to the fiery red of most prized kind.

**Optical Characters.**

Singly refracting. Indices of red and blue stones 1.716 to 1.720. Deep violet ones 1.730. Color dispersion weak, .020. Very slightly penetrated by X-rays.

**REMARKS.**—The common opaque spinels occur occasionally in igneous rocks, *picotite* with chromite, ceylonite with magnetite, but are more common in metamorphosed limestone, both contact and enclosed in schists.

The gem varieties are also most frequent in limestones and dolomites. Corundum is a common associate. The principal localities for gem spinel are the ruby-bearing limestones of Burma and Siam, which yield red varieties, and the gem gravels of Ceylon, which yield blue and violet varieties. Other localities are Expailly, France; Badakschan, Tartary; and in this country gem specimens have been obtained at Hamburg, N. J.; San Luis Obispo, Cal., and Orange County, N. Y. The crystals also occur in many localities in North Carolina, Massachusetts and near the New York and New Jersey line.

**BERYL.—Emerald, Aquamarine.** Described on p. 552.

**COMPOSITION.**— $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ .

This mineral furnishes the gems, *emerald*, *aquamarine*, *golden beryl*, *morganite* and *heliodore*.

Optical characters needing further detail are:

**REFRACTION AND INDICES OF REFRACTION.**—Doubly refracting, uniaxial and optically negative.

|                          | $\gamma$       | $\alpha$      | $\gamma - \alpha$ |
|--------------------------|----------------|---------------|-------------------|
| Range.....               | 1.572 to 1.598 | 1.567 to 1.59 | .005 to .008      |
| Colombian emerald.....   | 1.584          | 1.578         | .006              |
| Siberian aquamarine..... | 1.582          | 1.576         | .006              |
| Morganite.....           | 1.598 ?        | 1.59          | .008              |

**BIREFRINGENCE** weak .005. **DISPERSION** small.

**PLEOCHROISM** is usually faint but the South American emerald gives yellowish-green and bluish-green.

**EMERALD.**—Grass green, inclining rather to blue than yellow. It has no fire, is only moderately hard, usually flawed ("an emerald without a flaw"), and not as brilliant as some other green stones like hiddenite and demantoid, yet from ancient times its color has given it high rank.

The emerald of ancient times came from Upper Egypt. The locality was lost and refound in 1820 in the mountain range to the west of the Red Sea, where both emerald and beryl occur in micaceous and talc schists. The emeralds are inferior to those from Colombia.

The three great districts, discovered in Colombia in 1558 by the Spaniards soon after their conquest of Peru, were worked irregularly. That of Muzo, 75 miles north-

west of Bogota, is still working and is the chief source of the emeralds of the best grade. They are said to be sent chiefly to India to be cut. The localities of the other two were lost and one only was rediscovered in 1896, the other is still "lost."

Fine emeralds, but inferior to the Muzo stones, come from the Ural Mts. near Ekakrinenberg and the Salzburg Alps in Austria have yielded emeralds from the time of the Romans down.

Other localities are: Arendal, Norway; Topsham, Maine; Alexander Co., N. C.

**AQUAMARINE.**—"Green like the sea," that is deep, blue-green and grading from this towards colorless.

It is much used for brooches, and pendants, occurs in large quantities and fine grade both at Minas Novas and other parts of Brazil and at Mursinka, Urals, and of fine grade at Adun Tschilon, Siberia. Poorer grades are abundant.

**GOLDEN BERYL** of light and deep golden yellow is found in Macon Co., N. C., Delaware Co., Penn., etc.

**MORGANITE**, from Maharita, Madagascar, is of pure rose pink color.

**HELIODORE**, from German S. W. Africa, golden yellow by daylight, green by artificial light is said to be beryl.

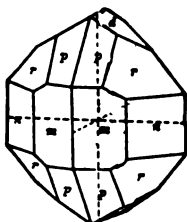
### CHRYSOBERYL.—Alexandrite, Cymophane.

**COMPOSITION.**— $\text{BeAl}_2\text{O}_4$ , (BeO 19.8,  $\text{Al}_2\text{O}_3$  80.2 per cent.), with oxides of chromium and iron giving the color.

**GENERAL DESCRIPTION.**—Pale green or yellowish tabular crystals; thicker deep emerald-green crystals, which by transmitted light are a purplish red; and rolled pebbles sometimes with an internal opalescence.

**CRYSTALLIZATION.**—Orthorhombic  $a : b : c = 0.470 : 1 : 0.580$ . Often flat contact twins with feather-like striations, Fig. 573.

FIG. 572.



Urals.

FIG. 573.



Haddam, Conn.

Alexandrite occurs in simple, Fig. 572, or twinned crystals showing unit pyramid  $p$  and prism  $m$  with brachy-pyramid  $r = (2a : b : 2c)$ ,  $\{121\}$ ; and prism  $n = (2a : b : \infty c)$ ,  $\{120\}$ . Supplement angles are  $mm = 50^\circ 21'$ ;  $nn = 86^\circ 28'$ ;  $pp = 40^\circ 7'$ ;  $rr = 72^\circ 17'$ .

**VARIETIES.**—*Alexandrite*, the deep green variety, which is so called because it was found in the emerald mines of the Urals on the birthday of the Emperor Alexander II. By daylight it is bluish to olive green in color and by lamp- or gas-light raspberry red, the cause of the change being the strong absorption of yellow and blue rays, the residual product varying with the source of light. For instance, with the tungsten light it is neither red nor green but intermediate.

Fine stones are scarce, the best coming from near Ekaterinberg, poorer from Tokowaja.

Larger stones of good quality come from Ceylon and others from the Weld River, Tasmania.

*Cymophane or Cats Eye.*—Yellowish-green and with minute parallel cavities. If cut cabochon with the rounded surface parallel to these a sharp line of opalescent light appears crossing the stone at right angles to the cavities, which seems to float in the surface as the stone is moved.

Principal locality is Ceylon, others come from Brazil.

### **Chrysoberyl or Oriental Chrysolite.**

*Chrysoberyl or Oriental Chrysolite.*—Color, pale yellowish green.

From Minas Novas, Brazil, and some from Rhodesia and Haddam, Conn. It is often confused with the yellow spodumene from Brazil.

**Physical Characters.** H., 8.5. Sp. gr., Alexandrite 3.644. Others 3.68 to 3.78.

**LUSTRE,** vitreous to greasy but less greasy than chrysolite.

**COLORS.**—As described under varieties.

### **Optical Characters.**

Biaxial (+). Axial plane (010). Acute bisectrix  $c$ .  $\gamma = 1.750$  to  $1.757$ ,  $\alpha = 1.742$  to  $1.749$ ,  $\gamma - \alpha = .009$ .

**PLEOCHROISM.**—Very strong in alexandrite in columbine red, orange and emerald green. The cymophane and oriental chrysolite show less strong pleochroism.

**ACTION X-RAYS.**—Rather easily penetrated.

**BEFORE BLOWPIPE, ETC.**—Infusible. In powder, is turned blue by cobalt solution. Insoluble in acids.

**REMARKS.**—Occurrences as described under varieties. No fine gems have been found in the United States, although the mineral occurs sparingly in Stowe, Peru and Canton, Me., New York City, and Greenfield, N. Y., Haddam, Conn.

## OTHER BERYLLIUM GEMS.

Beryllium which has no other economic value is the chief element not only in beryl and chrysoberyl but in the following species cut as precious stones.

**EUCLASE.**— $\text{Be}(\text{AlOH})\text{SiO}_4$ . Sea green or pale blue or colorless crystals with vitreous lustre. It takes a brilliant polish and when cut greatly resembles the aquamarine. It is very seldom cut, both because the crystals are valued by collectors and because of the very easy cleavage to which it owes its name.

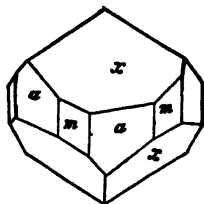
Found in Brazil at Villa Rica. Minas Geraes in the topaz locality, but never in the same druse. Also in diamond sand at Bahia. In Urals on Sanarka River in the gold washing and associated with topaz. Other localities are Peru and Tasmania.

**PHENACITE.**

COMPOSITION. —  $\text{Be}_2\text{SiO}_4$  (BeO 45.55,  $\text{SiO}_2$  54.45 per cent.).

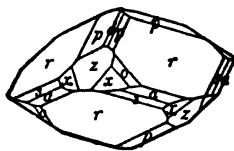
GENERAL DESCRIPTION. — Colorless, transparent, rhombohedral crystals, usually small, frequently lens-shaped. Sometimes yellowish and sometimes in prismatic forms. Harder than quartz.

FIG. 574.



Mt. Antero, Col.

FIG. 575.



Florissant, Col.

CRYSTALLIZATION. — Hexagonal. Class of third order rhombohedron, p. 54. Axis  $c = 0.661$ . Supplement angles  $xx = 75^\circ 57'$ ;  $rr = 63^\circ 24'$ . Optically +.

PHYSICAL CHARACTERS. — Transparent to nearly opaque. Lustre, vitreous. Color, colorless, yellow, brown. Streak, white. H. 7.5 to 8. Sp. gr. 2.97 to 3. Brittle. Cleavage, prismatic.

BEFORE BLOWPIPE, ETC. — Infusible and unaffected by acids. Made dull blue by cobalt solution.

The colorless water clear varieties when cut possess considerable brilliancy, about that of a white sapphire.

OCCURRENCE. — In granite pegmatites, quartz porphyry and mica schist. Cuttable stones are found in the Urals at the emerald mines at Stretinsk and at Miask. In Colorado at Pikes Peak and Topaz Butte and Mount Antero. In Brazil at Minas Geraes.

**BERYLLONITE.**— $\text{NaBePO}_4$ . A clear colorless mineral occasionally cut. The transparency and brilliancy of the stone resembles that of topaz, but lack of "fire" and softness are against it. H., 5.5.

OCCURRENCE. — Found loose among the disintegrated material of a granite vein at Stoneham, Maine.

**GADOLINITE.**— $\text{Be}_2\text{FeY}_2\text{Si}_2\text{O}_{10}$ , is occasionally cut as an opaque black stone.

**ZIRCON.—Hyacinth. Matura Diamonds.** Described on p. 314.

**COMPOSITION.**— $\text{ZrSiO}_4$ .

Transparent zircons possess the qualities which should make them rank high, namely, brilliancy, strong color dispersion, durability and agreeable colors including the fine golden yellow, aurora red to deep red and leaf green.

**COLORS AND COLOR NAMES.**—*Zircon*, brown, violet, green (leaf-green), blue.

*Hyacinth*,\* aurora red, sometimes deep red.

*Jacinth*, yellow—often golden.

*Jargon*, grayish-white or white, especially if not hard.

*Matura Diamonds*, colorless (usually made so by heating).

**Notable Characters.**

The characters following would seem to indicate at least two structurally different substances, one isotropic or nearly so, the other tetragonal.

**CRYSTALLIZATION.**—Sharp, tetragonal crystals. The Ceylon pebbles, however, show no crystal faces.

**REFRACTION AND INDICES OF REFRACTION.**—Doubly refracting, uniaxial and positive, but with wide differences, some with both indices close together and ranging from 1.79 to 1.84. Others with ordinary ranging from 1.92 to 1.93 and extraordinary 1.96 to 1.99.

**BIREFRINGENCE.**—In some almost zero, in others very strong, as much as .06.

Other characters are:

**LUSTRE.**—Adamantine—approaching that of the diamond. It is increased by heating.

**COLOR DISPERSION.**—Very high, .038, diamond being only .044. Hence considerable fire, though inferior to that of the diamond.

**ABSORPTION SPECTRUM.**—Often show lines characteristic of uranium, corresponding to wave-lengths 651, 588 and 512. Many zircons do not show the bands.

**PLEOCHROISM.**—Exceedingly faint even in most highly colored stones.

**ACTION X-RAYS.**—Practically opaque.

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\* *Hyacinth*, from an old Indian word originally used for sapphire, then especially for yellow sapphire and generally for other yellow stones, then more definitely for yellow zircon and garnet. Now queerly twisted to the more red stones while the yellow are called by another spelling of the same word, *Jacinth*.



**LUMINESCENCE.**—Sometimes luminescent during grinding or if heated on Bunsen burner.

**SPECIAL TEST.**—Under the microscope many zircons show a "feathery" appearance called "ratine" and described as resembling a liqueur poured in water.

**BEFORE BLOWPIPE, ETC.**—Infusible but at about 500° C., the color is weakened and may be destroyed. The green may become fine yellow and the pale brown become colorless. Some colorless stones from Tasmania become brown on heating. Insoluble in acids.

**OCCURRENCE.**—The finest stones come from Ceylon. Fine red stones are brought from central Queensland and from New South Wales. Small hyacinths and deep red stones are found at Expailly, France. Rounded pebbles in Tasmania. Other localities in Germany and Bohemia.

### **TOPAZ.—Precious Topaz.** Described on p. 523.

**COMPOSITION.**— $\text{Al}_2\text{Si}_2\text{O}_7\text{F}_{10}$ . The best known topaz is yellow or sherry to brownish yellow. Decided blues are called *Brazil sapphires*. Red or pink topaz (usually the result of heating the Brazil yellow stone) are known as *Brazil rubies*.

Much of the so-called topaz is yellow quartz (citrine or burnt amethyst). This though unsatisfactory can claim old usage, for it is generally admitted that topaz first meant a yellow chrysolite from Topazion, an island in the Red Sea, and later the name stood for any yellow gem and in this sense it is still used by the jewelers.

Brazil and the Urals are the chief sources of gem topaz.

*Brazil* in decomposed rock and gem gravels at Ouro Preto, Villa Rica and Minas Novas, as wine yellow, blue, pinkish and brownish yellow, light green and colorless.

*Urals.*—Fine green and blue from Alabastika, Perm and Miask. Reddish from gold washings at Troisk, pale brown from near Nertschinsk.

Other localities are: *Cairngorm, Scotland*. Sky blue pebbles. *Tasmania*. Colorless, sea-green and blue. *Japan*. Colorless and bluish. San Luis Potosi, *Mexico* and Pike's Peak, *Colorado*. Colorless.

**DANBURITE.**—A borosilicate of lime, occurring in considerable quantity as pale wine colored orthorhombic crystals at Russell, N. Y. Has been found in Japan as colorless transparent crystals greatly resembling topaz which when cut show considerable brilliancy. H., 7.5. Sp. gr., 2.97 to 3.02.

### **TOURMALINE.—Rubellite, Etc.** Described on p. 524.

**COMPOSITION.**— $\text{R}_3\text{B}_3(\text{SiO}_3)_4$ . R chiefly Al, K, Mn, Ca, Mg, Li. This mineral yields numerous transparent stones of many colors.

The green and red and brown are most cut. The variety names\* are purely color names and are not much used; more often the name tourmaline with the prefix green, red, etc.

Oddities are cats eye tourmaline and green tourmaline, ruby red in artificial light (Ekaterinenberg).

The most notable characters are the strong pleochroism and absorption, the development by friction or heat of + and - charges of electricity at opposite ends of the  $c$  axis, and the fusibility sometimes easy, sometimes difficult.

**OCCURRENCE.**—The great localities are Minas Novas and Arrasuhy. Brazil (green and red), Ekaterinenberg and Transbaikal, Russia (pink, blue, green and red); Pala and Mesa Grande, California (pink, green and blue), Ceylon (the yellow "turumali" from which the name tourmaline came). Other localities are Burmah, Madagascar, Mt. Mica and Auburn, Maine.

**SPODUMENE.**—**Hiddenite, Kunzite.** Described on p. 429.

**COMPOSITION.**— $\text{LiAl}(\text{SiO}_3)_2$ , with traces of chromium, or manganese in the colored varieties.

This species yields stones with beautiful lustre.

#### VARIETIES AND THEIR OCCURRENCE.

**HIDDENITE.**—Yellowish to deep emerald green tinged with yellow. Color attributed to chromium. Ends of crystals usually different color.

From Stony Point, N. C., at the Emerald Mine. About 200 carats were found. The largest crystal would have yielded a stone of  $5\frac{1}{2}$  carat.

**KUNZITE.**—Lilac, pink, colorless. The crystals often pale, observed through the prism and rich amethystine observed transversely. Color attributed to manganese.

Found near the deposit of colored tourmalines at Pala, California. One crystal, the Pala Princess, weighs 2,444 $\frac{1}{2}$  carats.

**SPODUMENE.**—Yellow to colorless with a touch of green.

Found in Brazil, Minas Geraes, with chrysoberyl (often confused with it).

#### Notable Characters.

*Hiddenite* is strongly pleochroic. *Kunzite* is pleochroic, in violet and yellow, or with paler crystals, pink and nearly white.

*Kunzite* becomes luminescent with X-rays or radium or ultra-violet light

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\* *Achroite*—colorless. *Indicolite*—indigo blue or dark blue. *Brazilian Sapphire*—lighter blue but never sapphire tinted. *Rubellite*—rose red and pink. *Siberite*—violet red. *Siberian ruby*—dark red. *Brazilian emerald*—dark green but never emerald. *Ceylon peridot*—yellow. *Brazilian peridot*—yellowish green. *Ceylon chrysolite*—greenish yellow. *Schorl*—black.

**CHRYSOLEITE.**—Olivine, Peridot. Described on p. 513.**COMPOSITION.**— $(\text{Mg.Fe})_2\text{SiO}_4$ .

Chrysolite, the golden stone of Pliny, was yellow topaz and topazius was chrysolite. This has gradually been inverted. Peridot is of uncertain origin and is apparently the same as Pliny's callaina.

PERIDOT, sometimes called the evening emerald, is deep bottle green "like tourmaline with a dash of yellow" to less attractive olive green. The approved color, "like that seen in looking through a delicate green leaf."

CHRYSOLEITE is pale greenish yellow.

**Notable Characters.**

The stones are too soft for ring stones (H., 6.5) but have a very brilliant somewhat oily lustre when polished.

The *Birefringence* is .036, higher than most gem stones and usually easily recognized in a cut stone by the doubling of edges as seen through the table face.

The *Pleochroism* is faint, one image more yellow than the other, stronger in olive-colored stones. *Peridot* may give straw yellow and green.

**ACTION OF HEAT.**—Dark stones are made lighter in the oxidizing flame, becoming more yellowish brown and in the reducing flame more green.

**OCCURRENCE OF CUTTING MATERIAL.**—Most of it comes from the Island of St. John in the Red Sea. Crystals yielding stones up to 80 carats in weight are found. It is believed that this is the long lost source of the fine, large stones so common in European altar decorations.

*Arizona and New Mexico* furnish dark yellowish green peridot without crystal form. *Queensland and Upper Burma* supply light green stones.

**STONES RESEMBLING CHRYSOLEITE.**

**TITANITE OR SPHENE.**— $\text{CaTiSiO}_6$ . This mineral, described p 525, furnishes stones of great brilliancy and fire of about the colors of chrysolite and brown topaz. They are, however, too soft for much wear H. = 5.5.

**COLORS.**—Yellowish green, suggesting chrysolite or demantoid and brownish yellow resembling topaz.

**LUSTRE.**—Very brilliant, almost adamantine.

**PLEOCHROISM.**—Vivid with twin tints, green, yellow and reddish.

**REFRACTION AND INDICES OF REFRACTION.**—Double refracting, biaxial positive. The smallest index varies from 1.888 to 1.917, the largest from 1.914 to 2.053.

**BIREFRINGENCE.**—.12. So large that the doubling of the opposite edges when viewed through one of the faces is obvious to the unaided eye, even in a thin stone.

**COLOR DISPERSION.**—.051. Greater even than that of the diamond and resulting in a great deal of "fire."

**OCCURRENCE OF CUTTING MATERIAL.**—*Switzerland*, in St. Gothard; *Tyrol*, Pfitschthal; *New York* at Tilly Foster in yellow to brown; *Pennsylvania*, Bridge-water.

**DIOPSIDE.**— $\text{MgCa}(\text{SiO}_3)_2$  Iron is usually present in small amounts, described p. 506.

This mineral, a member of the group of monoclinic pyroxenes occasionally occurs in transparent specimens worthy of cutting. Light to dark oily leaf green or bottle green.

**OCCURRENCE OF CUTTING MATERIAL.**—Light green crystals in Ala Piedmont and DeKalb, N. Y. Dark green crystals from Zillerthal, Tyrol.

**ENSTATITE.**— $(\text{Mg}, \text{Fe})\text{SiO}_3$ , described p. 504, is now found as transparent green material accompanying the diamonds in South Africa and is cut in faceted stones and sold as the Cape green garnet.

**EPIDOTE.**— $\text{Ca}_2\text{Al}_2(\text{AlOH})(\text{SiO}_3)_3$ , described p. 528, is of a peculiar shade of yellowish green, similar to that of the pistachio-nut. By transmitted light in directions at right angles the stone will appear respectively green and brown, by reflected light is nearly black.

Bauer states only one locality furnishes material which is transparent enough to be worth cutting, namely, Knappenwand, Untersulzbachthal, Tyrol.

**PREHNITE.**— $\text{H}_2\text{Ca}_2\text{Al}_3(\text{SiO}_3)_4$ . This mineral described p. 535, occurs in Namaqua land in beautiful crystals which furnish green stones like chrysolite and others resembling chrysoprase. The material from the many other localities is only translucent and little used.

**MOLDAVITE.**—A green glass found in Bohemia and Moravia and resembling green bottle glass, was long suspected to be the product of old and forgotten glass factories.

The finding of the same material deep down in the garnet mines of northern Bohemia show that it far antedates man and the present supposition is that the fragments are glassy bombs due to the bursting of a meteorite which fell in near the end of the Tertiary period.

**GARNET.**—Demantoid, Almandine, Etc. Described on p. 509.

**COMPOSITION.**— $\text{R}''_3\text{R}'''_2(\text{SiO}_3)_3$ .  $\text{R}''$  is Ca, Mg, Fe or Mn.  $\text{R}'''$  is Al, Fe''' or Cr, rarely Ti.

#### GEM VARIETIES AND THEIR OCCURRENCE.

**DEMANTOID**, so called from its diamond like lustre and fire is the most highly valued garnet. It is also called olivine and uralian emerald, and is a variety of andradite,  $\text{Ca}_3\text{Fe}_2(\text{SiO}_3)_3$ , of an emerald green to olive green color (more yellow than the true emerald) with brilliant lustre and the greatest color dispersion (fire), .057, known. Its index is very high, 1.88 to 1.89, but it is soft, 6 to 6.5.

It is found in the Sissersk district, western side of the Urals and in Piedmont.

**ESSONITE** or Hessonite, reddish brown to orange, **CINNAMON STONE** golden yellow to brown, and **HYACINTH** or false hyacinth, golden yellow, are all essentially alike and are of the general formula  $\text{Ca}_2\text{Al}_2(\text{SiO}_3)_3$ . They are somewhat softer than

other garnets, 7, but take a good polish and are more brilliant by artificial light. A peculiar granulated appearance under the glass is very characteristic.

The best are from the Ceylon gravels, also found at San Diego Co., California, and formerly in Switzerland.

**ALMANDINE**, known also as Syriam garnet, Adelaide ruby, and Siberian garnet, is violet, reddish violet, crimson and brownish red. It loses brilliancy in artificial light and was formerly much used cut "cabochon." It is remarkable for its characteristic absorption spectrum and is of the type  $\text{Fe}_2\text{Al}_2(\text{SiO}_4)_3$ .

Formerly from Alabanda, Asia Minor, whence the name. Various parts of India and Burmah, Brazil, Uruguay, Australia, U. S. A., German East Africa.

**RHODOLITE**.—A rose pink variety from Macon Co., N. C., equivalent to two molecules pyrope to one of almandine.

**PYROPE**, the most used garnet, is also known by many misleading names, like Cape ruby, Colorado ruby, while not a clear transparent stone often occurs fire red and blood red. Light-colored stones backed by colored glass constitute the fire doublets. It is of the type  $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ .

Occurs in enormous quantities in Bohemia near Teplitz as small red stones with tinge of yellow. Also in the "blue ground" of the diamond mines at Kimberley, and in Arizona, Colorado, Australia, Rhodesia, etc.

**SPESSARTITE** of the type  $\text{Mn}_2\text{Al}_2(\text{SiO}_4)_3$  has furnished a few very fine stones; it is more brilliant than hyacinth and of a peculiar brownish red color.

Occurs at Spessart, Germany, Ceylon and Amelia Co., Va.

#### PHYSICAL AND OPTICAL CHARACTERS OF GARNETS.

**SPECIFIC GRAVITY**.—3.55 to 4.20 or, by varieties, essonite, 3.6–3.7; pyrope, 3.7–3.8; rhodolite, 3.79–3.87; almandine, 3.9–4.2; spessartite, 4–4.3; demantoid, 3.85.

**HARDNESS**.—A little harder than quartz. Essonite, 7+; pyrope, 7+; rhodolite, 7+; almandine, 7.5; spessartite, 7.5–8; demantoid, 6–6.5.

**LUSTRE**.—Vitreous but takes good polish. The lustre of essonite is more brilliant by artificial light. On the other hand, almandine loses brilliancy.

**REFRACTION AND INDICES OF REFRACTION**.—Singly refracting and yet practically always with some local double refraction giving between crossed nicols every 90° gradual transitions from light to darkness. Essonite, 1.75–1.78; pyrope, 1.75–1.78; rhodolite, 1.76; almandine, 1.77–1.81; spessartite, 1.79–1.81; demantoid, 1.88–1.89.

**COLOR DISPERSION**.—Essonite, .028; pyrope, .027; almandine, .024; demantoid, .057.

**ABSORPTION SPECTRUM**.—Almandine and rhodolite show lines corresponding to wave-lengths 570 to 585 and 510–495.

**ACTION X-RAYS**.—Essonite almost unpenetrated.

**QUARTZ**.—Amethyst, Citrine, Etc. Described on p. 484.

**COMPOSITION**.— $\text{SiO}_2$ .

#### COLOR VARIETIES AND THEIR OCCURRENCE.

**ROCK CRYSTAL**.—Colorless and water clear. The crystallus of the ancients, from the idea that it was ice permanently frozen. It was made into drinking cups and solid finger rings for the Romans, and balls of crystal were carried in the hands for coolness and used also as a lens for cauterizing and for kindling fire.

At present rock crystal is cut into imitation diamonds, such as Lake George, Bristol, Irish, etc., diamonds. The chief localities are Sierra do Cristaes, Brazil, Madagascar and Switzerland, others are France, Hungary

**AMETHYST**, from a Greek word meaning "wineless,"\* is purple to violet, often irregularly diffused. "The rosy hue shining out from the purple." It is less brilliant by candle light.

Amethyst invariably shows on fracture curious ripple marks, due to the fact that it is always composed of alternating right- and left-handed crystals.

Up to 1600 and even in the nineteenth century it kept a high rank. "Queen Charlotte's necklace, valued at \$10,000, would possibly now be valued at \$500.00."

Fine amethysts come from Rio Grande do Sul, Brazil, and from Uruguay and Siberia. Other localities are numerous, such as Ceylon, India, N. C., Ga., Penn. In preparing for market the poorer colored portions are chipped from the pebbles and crystals and the fine-colored bits selected and sold.

**CITRINE**, from citron, alluding to the brownish-yellow to yellow color, is commonly called by jewelers topaz. Much of the yellow quartz sold is, however, burnt amethyst or burnt smoky quartz. It is chiefly from Brazil.

**CAIRNGORM**, from the locality Cairngorm, in Scotland, is often sold as Scotch topaz.

**SMOKY QUARTZ**.—The Spanish variety from Sierra Morena, Spain, turns yellow on heating and is sold as Spanish topaz. "Alençon diamonds" were smoky quartz.

**ROSE QUARTZ**, named from its color, is not found in crystals. The best comes from South Dakota, Paris, Me., Katonah, N. Y. Other localities are Madagascar, Bavaria and Urals. Sometimes called Bohemian ruby.

#### VARIETIES DUE TO INCLUSIONS OR STRUCTURE AND THEIR OCCURRENCE.

**PRASE OR MOTHER OF EMERALD**.—Originally a pale green stone, colored by included leek green fibres of actinolite and supposed at one time to be the matrix of the emerald. It was valued because it was supposed to possess the powers of the emerald to a less degree (for instance, to lose its color on contact with poison).

Although the ancient locality is unknown it occurs at Halbachthal, Salzburg, Breitenbunn, Saxony, Finland and Scotland.

**ADVENTURINE QUARTZ**.—The name from "Aventura"—an accident—was first applied to a glass produced by accidentally spilling copper filings into the melted glass. This material, now sold as goldstone, is somewhat similar to quartz, containing spangles of mica, hematite, etc. The favorite colors are golden brown, reddish and greenish. The green from the Altai Mts. is much valued in China.

**STAR QUARTZ**.—Showing a six-rayed star. Usually massive rose or milky quartz.

**CAT'S EYE**.—Translucent greenish or greenish gray due to asbestos.

Chiefly from Ceylon and India and an inferior grade from Fichtelgebirge, Bavaria.

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\* Pliny states: "The lying Magi hold that these gems are an antidote to drunkenness and take their name from this property," and then he suggests the name to have been given because the color approximated but did not reach wine color. King suggests the word is a corruption of the Persian word Shimest.

It is imitated by "bleached" tiger's eye. It was a valued specific for croup, sore eyes, colic, and other troubles.

**TIGER'S EYE AND FALCON'S EYE.**—There was found in Griqualand, West South Africa, large quantities of an altered fibrous mineral, crocidolite, consisting chiefly of quartz. While sold originally as crocidolite it is now sold as tiger's eye if tawny yellow in color and as falcon's eye when deep blue in color.

A similar but paler blue altered crocidolite from Salzburg, Austria, is called siderite or sapphire quartz.

**DUMORTIERITE QUARTZ.**—Is cut from the California and Arizona localities.

**ANDALUSITE.** *Composition.*  $\text{Al}_2\text{SiO}_4$ . Described p. 518. Transparent varieties are remarkable for strong pleochroism and for a red color visible from the interior in addition to the brown or green body color.

#### Optical Characters.

Biaxial (—),  $\gamma$ , 1.643;  $\alpha$ , 1.632;  $\gamma - \alpha$ , .011. Strongly pleochroic. Brown shows reddish brown and greenish yellow. Green shows olive green, yellow and red.

*Occurrence.*—Good stones are found at Minas Novas, Minas Geraes, Brazil, and in the gem gravels of Ceylon.

**AXINITE.**—A borosilicate of calcium and aluminum.

Triclinic in acute wedge-shaped (axe-shaped) crystals. The triclinic symmetry very evident, Fig. 5. The colors are clove brown to smoky violet, sometimes cherry red, and the lustre a strong vitreous which takes a good polish.

OPTICALLY biaxial (—) with  $\gamma = 1.68$ ,  $\alpha = 1.67$ ,  $\gamma - \alpha = .009$ , and strong pleochroism, giving violet, green and brown.

**BEFORE BLOWPIPE, ETC.**—Violet changes to brown, then becomes colorless. Fuses easily. Gives green flame of boron. Insoluble in acid, but gelatinizes after fusion.

*OCCURRENCE.*—Violet crystals from Roseberry, Tasmania. Brown to red crystals from Bourg d'Oisans, Dauphiny. Reported from San Diego Co., Cal.

Other minerals occasionally cut as transparent stones are *staurolite*, *chondrodite*, *datolite*, *various zeolites*, *fluorite*, *apatite*, *piedmontite*, *cancrinite*, *willemite*, *cassiterite*.

## B. THE TRANSLUCENT TO OPAQUE STONES.

### TURQUOIS.—Turkis or Turkish Stone.\*

**COMPOSITION.**— $\text{Al}_2(\text{OH})_2\text{PO}_4 \cdot \text{H}_2\text{O}$  and always contains some copper and iron which give it color.

**GENERAL DESCRIPTION.**—Sky blue to green opaque nodules or veins, also in rolled masses.

In general not crystalline but apparently colloidal and somewhat porous. It is the only opaque stone which ranks as a precious stone, and was the Callais of Pliny which "resembled Lapis Lazuli but whiter and of the hue of the sea where it is shallow."

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\* The gem came from Persia to Europe by way of Turkey.

It has always been the favorite stone in Persia and in Europe in the middle ages it was most popular, the preference being for the greener shades.

### **Physical Characters.**

**SPECIFIC GRAVITY.**—2.75 to 2.89. Los Cerillos, 2.71 to 2.82. Surface stones, 2.42 to 2.65.

**HARDNESS.**—Less than 6.

**LUSTRE.**—Dull and wax-like but takes a good and fairly durable polish.

**COLOR.**—Sky blue to greenish blue or when iron prevails, yellowish green to apple green or pea green. The colors are more blue in artificial light than daylight. All fade in time, and the color is injured by perspiration, grease, liquids and heat.

### **Optical Characters.**

Index of refraction about 1.61. Not penetrated by X-rays.

**BEFORE BLOWPIPE, ETC.**—Infusible but colors the flame green. In closed tube cracks, flies to pieces, yields water and becomes brown. Soluble in hydrochloric acid, the solution becoming fine blue with ammonia.

**REMARKS.**—A secondary phosphate due to action of phosphate solutions on aluminous material.

The best stones still come from eastern Persia near Nishapur in seams in a brecciated trachyte. Inferior specimens come from Asia Minor at Serbal in Sinai Peninsula, Turkestan and Kirghiz.

Ancient Aztec workings exist near Los Cerrillos, New Mexico, and good stones were obtained near these at Turquoise Hill. Other old workings in San Bernardino Co., Calif., yielded pale colored stones and Nevada, Nye Co., yields a dark sky blue to pale blue. Often mottled or "turtle back" material. Arizona, Colorado, Mexico also have yielded material.

### **IMITATIONS OF TURQUOIS AND SIMILAR STONES.**

Turquoise can be colored by placing in a solution of Berlin blue under an air pump and exhausting the air. Turquoise colored by Berlin blue is grayish blue by artificial light and changes color in ammonia.

By precipitating the proper proportions of hydrous phosphate of aluminum and copper phosphate and pressing hydraulically while still wet a product can be made equal or superior in color to natural. Slight differences of hardness, specific gravity and indices of refraction exist but the principal distinctions are that if heated real turquoise splinters, flies to pieces and turns brown, and synthetic turquoise fuses quietly to a black glass. In water synthetic turquoise becomes deeper blue and the surface shows many little cracks.

**ODONTOLITE OR BONE TURQUOIS.**—In the vicinity of Simor, Lower Languedoc, France, are found numerous fossil teeth and bones, of the mastodon and dinotherium, which have taken up phosphate of iron and become bluish gray in



color but on heating become a beautiful blue. Occasionally also they are found colored green by copper salts. Some similar material found in Siberia is also blue colored.

The material strongly resembles turquoise, but differs from it in that its color by candle light is dull and gray; under the microscope the organic structure is evident; it effervesces when touched with acid, and it yields a bad smell on ignition.

**CHRYSOCOLLA**, p. 372, is rarely cut unless contained in some harder substance like quartz or chalcedony. Occasionally translucent blue and bluish green specimens are cut. It has an enamel-like texture and some blue specimens resemble turquoise.

**VARISCITE**.— $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$  in bright green to bluish green, compact, opaque, rounded masses and veins resembling turquoise and suitable for cutting.

It may be the oldest gem.\* It is found in Cedar Valley, Utah and in several parts of Nevada.

**LAZULITE**.—Blue Spar. A complex phosphate of aluminum and other bases. The massive material is sometimes cut and could readily be mistaken for turquoise. In Germany it is known as "Blauspäth."

The principal occurrences are Kriglach, Styria; Werfen, Salzburg; Zermatt, Tyrol; Sinclair Co., N. C., and Graves Mt., Ga.

**SMITHSONITE**.— $\text{ZnCO}_3$  described on p. 300.

The sacred stone of the Aztecs "Chalchihuitl," long supposed to have been turquoise, is now thought to be the beautiful banded azure blue smithsonite of the Yaabellita mine, Mexico. Green smithsonite occurs at the same mine.

## OPAL. Described on p. 487.

**COMPOSITION**.— $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ , ( $\text{H}_2\text{O}$ , 5 to 12 per cent.). "Made of the glories of the most precious gems," "fairest and most pleasing of all jewels" is Pliny's description of opal. The beauty is due not to the color of the stone but to varying brilliant interference colors, produced by thin films of air or of other opal in the cracks developed during the drying of the original jelly-like mass.

On the basis of color of the stone opals are broadly divided by jewelers into:

**WHITE OPALS**, colorless, milky yellowish and other light tints.

**BLACK OPALS**, dark gray, blue and nearly or quite black.

**FIRE OPALS**, reddish or orange colored.

Many names have been used based on the predominance of one or the other *interference* color; these are little used now. An example is harlequin opal, with the interference colors in small, regular angular patches of every hue.

In others some peculiarity in structure is the basis of a name.

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\* There was found in an Old Celtic grave at Mane er Hrock in Brittany a considerable number of rounded beads from the size of flaxseed to that of a pigeon's egg, from apple to emerald green in color, and often flecked with white or blue. The composition is close to variscite. The remarkable thing is that they are more transparent, and of more beautiful colors than any specimens found elsewhere.

**HYDROPHANE.**—The cracks being filled with air fail to give play of color but if filled with a denser medium, by dropping in water the colors appear.

**CACHOLONG**, a milky white almost opaque variety, which adheres to the tongue.

**GIRASOL.**—Almost transparent but with a wave of blue light, something as in moonstone.

**OCCURRENCE.**—The ancient source of the best is said to have been India. No such gem comes from there now. The mines in Hungary near Czernovitz yielded much slightly yellowish opal and some fine, and were long the only important source.

In the early eighties the rich blue opals were discovered in Queensland, Australia, in thin veins through a brown jasper, and a little later bright yellowish opals were found in pipes of jasper in a sandstone rock in West Queensland.

In 1889 white opals of fine quality were found at White Cliffs, New South Wales, in Cretaceous rocks replacing other minerals, bones and wood, and filling cavities. In ten years these were exhausted. In 1904 at Lightning Ridge, New South Wales, the dark-colored so-called black opals were found in essentially the same formation as at White Cliffs. These also are practically exhausted.

*Mexico* yields many fire opals and some white opals which are sometimes faceted, sometimes cut with matrix. They are more translucent than other opals and are said to lose their play of colors.

In Humboldt County, *Nevada*, opalized wood, often of dark color but with beautiful play of colors is found. It has a tendency to crack during and after cutting.

**CHALCEDONY.**—*Carnelian Onyx, Etc.* Described on p. 486.

**COMPOSITION.**—Silica with occasionally a little water. The earlier gems were engraved rather than cut and no substance has proved as suitable or durable as chalcedony. Before the coming of the sapphires and other transparent gems from India and Ceylon, carnelian and onyx were much used by the Romans and through the Renaissance period for seals and cameos. The beeswax then used did not stick to it. "Signeth very faire without any of the wax sticking to it."

A pale blue variety, sapphirine, was used much earlier in Babylonian and Persian cylinders and Etruscan scarabs.

The best known varieties are:

**CHALCEDONY** or *Girasol*, white, gray and "tendon" color.

**CARNELIAN.**—To the Romans dull brick red and little value, now the name for clear red.

**SARD.**—To the Romans the bright clear red, now the name for brownish-red.

**CHRYSOPTASE** (golden leek), an apple green variety, colored by nickel.

**BLUE CHRYSOPTASE.** Chalcedony containing chrysocolla.

**BLOODSTONE OR HELIOTROPE.** Deep leek green with spots of red jasper. Said to have been used as a mirror in detecting solar eclipses. Much used in the Byzantine period for sacred carvings, the red jasper being said to be the Savior's blood.

**AGATE.**—Variegated chalcedony in clouds, bands, spots or layers. Named for the river Achates in Sicily.

**MOSS AGATE AND MOCHA STONE**, with moss-like inclusions.

**ONYX.**—Originally oriental alabaster, later the tricolored agate used for signet rings. Pliny says "a white mark on sard like the human nail placed upon flesh and both of them transparent."

The tricolored agate was cut across parallel layers so as to give two bands of dark brown with a layer of colorless transparent between. This was long the favorite signet stone.

Onyx to-day is an agate with regular, even planes of different colors, especially white and black or white, brown and black, and was used much for cameos.

**SARDONYX.** Onyx with one of the layers of sard. Pliny's perfect sardonyx was base black or chocolate; middle opaque, fatty white; surface brown or red.

**OCCURRENCE.**—India is noted for its fine carnelians and agates. Brazil furnishes the "carnelian" so-called free from iron, which is colored and polished at Idar\*

Uruguay furnishes much material and agate and chalcedony are found in a great many localities in America, such as Agate Bay, Lake Superior, Colorado and through the Rocky Mountains. *Agatised wood* comes from Arizona. *Chrysoprase* from Venus Hill, California, and *Blue Chrysoprase* from Globe, Arizona.

## JADE.†

The great "Nephrit-Frage" arose because jade weapons apparently composed of Asiatic jade were found in many parts of Europe, and no localities for raw jade were known. More careful search found raw jade in Silesia, Siberia, Italy, and elsewhere.

Possibly only because its toughness made jade suitable for delicate carving and possibly from superstition, China and Japan and to some extent India and ancient Mexico grew to value the jade beyond other stones and to carve from it with immense labor vessels, figures, beads and amulets. The plundering of China has brought many of these to Europe and America.

In Europe in the early part of the seventeenth century it was enormously valued. Deboot says a piece no larger than a thaler sold for 100 pounds. This seems to have been due to the powerful medicinal properties attributed to it. Both worn as an amulet and administered as a powder, it was held to cure kidney troubles.

In 1863 Damour showed that while most of the light-colored jade objects were, as supposed, the variety nephrite of the mineral amphibole, many of the more valued green jades, though much

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\* The white chalcedonies formerly found at Idar and the so-called Brazilian carnelian now worked there are free from iron. They are therefore easily given other colors by different solutions and processes, the colors including black, sard brown, sard onyx, lemon yellow, blue, deep blue, green.

† Jade for various reasons has an extensive literature and has been more valued by various races and for more various reasons than perhaps any other stone. In the Stone Age the man with the tough jade weapon was master of the man with weapons of any other material, and jade weapons were valued and sought for with a care not since equaled.

like nephrite in toughness and translucency, were of a totally different composition and were definitely harder and heavier. To these he gave the name jadeite and a third name chloromelanite, essentially a jadeite rich in iron. In these the constant characters were extreme toughness, lack of brilliancy and in general translucency, and the dominant color was from white to green. Although two distinct minerals, it has seemed most convenient to discuss them as if varieties of one substance, broadly called jade.

COMPOSITION.—*Nephrite*  $\text{Ca}(\text{MgFe})_3(\text{SiO}_3)_4$ , *Jadeite*  $\text{Na}_2\text{Al}_2(\text{SiO}_3)_4$ .

NAME.—Jade is from the Spanish *hijada* = kidney. Nephrite is the Latin word for kidney. Jadeite is Damour's name for the new species discovered by him among the jades.

SPECIFIC GRAVITY.—Nephrite 2.97 to 3.18, the lighter colored being the lower specific gravity. Jadeite 3.3 to 3.35, but lower when altered.

HARDNESS.—Nephrite 5.5, Jadeite 6 to 7.

TOUGHNESS.—Nephrite very difficult to break. Jadeite equally tough when fine fibrous, less so when granular.

COLORS.—*Nephrite*: Turkestan, yellowish gray to white or greenish; Silesia, dark green to bluish green; New Zealand, dark green; Alaska, dark green to nearly black. *Jadeite*: Burma, white, gray, green, brown or red, often with streaks of emerald green.

LUSTRE.—Dull, oily, not brilliant, even when polished.

CRYSTALLIZATION AND STRUCTURE.—Both are monoclinic. In nephrite the microscopic crystals are confusedly interlaced fibres, which in the New Zealand material are sometimes coarser and recognizable. Jadeite occurs in both fine fibrous and granular masses.

CLEAVAGE.—Not recognizable except in thin sections. In nephrite cleavages of  $54^\circ 38'$  have been detected. In jadeite cleavages of about  $86^\circ$  have been detected.

REFRACTION AND INDICES OF REFRACTION.—Though both are doubly refracting, this is not determinable in the cut stone. The indices average, nephrite about 1.61, jadeite about 1.67.

ACTION X-RAYS.—Nephrite nearly opaque.

BEFORE BLOWPIPE, ETC.—Nephrite is unchanged at red heat, but fuses at 4 to a colored glass. Jadeite fuses very easily (2.5)

with a strong yellow flame to a transparent bubbly glass. Neither is readily attacked by hydrochloric acid.

**OCCURRENCE.**—*Nephrite* occurs in great masses twenty to forty feet thick, in gneiss, in Turkestan, in the valleys of the Karakash, Yarkand and Kashgar rivers. These are the sources of most of the light-colored nephrite with specific gravity 2.9 to 3. It is said to occur in several provinces in China, and it occurs in place, in serpentine on D'Urville Island, New Zealand, and also as numerous boulders of dark green, light green, and gray color. Other occurrences are: as boulders near Lake Baikal, Siberia; both as boulders and in place in Silesia; in New Guinea and Alaska.

*Jadeite* is found as boulders and with albite forming light colored layers in green serpentine in Mogoung, Upper Burma. The serpentine is in sandstone. It is nearly all sold to China and amounts to about \$250,000 per year. Jadeite is said to occur also in China and Thibet and to have been found in place in Italy.

#### JADE-LIKE MINERALS.

**CALIFORNITE**, a compact variety of vesuvianite, described on p. 511, has the appearance of a jade and polishes well. It is found in Siakiyou and Fresno Counties, California. The pieces are in some cases as much as 5 feet square and 2 feet thick, of excellent quality for polishing. The associated rock is precious serpentine.

**SERPENTINE.**— $\text{H}_2\text{Mg}_2\text{Si}_2\text{O}_6$ , with replacement by Fe. Described, p. 544.

Although a soft mineral serpentine takes a good polish and is durable and its frequent occurrence in translucent varieties of bright oil green to paler green resembling jade and the ease with which it is worked has resulted in its very extensive use for decorative purposes, art work, cameos, intaglios, etc. At Zöblitz, Saxony, it is the basis of a large industry.

Special varieties are: Williamsite, apple green, nearly transparent. Bowenite or Tangiwai, rich to pale green. Satellite, a dull green fibrous variety, mixed with chalcedony and cut as cat's eye. Green stone of South Africa, malachite green.

Localities are very numerous. Snarum, Norway; Miask, Urals; Newburyport, Mass.; Milford Sound, New Zealand, and Smithfield, R. I., Texas, Pa.; Venus Hill, Cal. (satellite).

#### LAPIS LAZULI.

This stone, the sapphire of the ancients and the only stone of value in Egypt at the time of the early Pharaohs, is not a mineral but a complex of calcite, colored by three blue aluminum silicates. One lazurite, an ultramarine, involving sodium sulphide, one haüynite, and the third sodalite. It is a deep blue, sometimes purplish, and often spangled with little crystals of pyrite. The Chilian variety is a yellower blue and has white or gray flecks.

**OCCURRENCE.**—The Egyptians are said to have had mines in Ethiopia. The oldest known mines are in the Kokseha Valley, Badakshan, Afghanistan, and it is also said to occur in India at Sadmoneir and Bijour. Other localities are Lake Baikal, near the source of the Koultouk; the Chilean Andes, and Thibet.

**IMITATIONS OF LAPIS LAZULI AND SIMILAR STONES.**

**IMITATIONS.**—The best is a jasper from Nunkirk, stained blue. It is called German lapis and perfectly imitates the Chilean, but fades in time.

**AZURITE**, p. 371, is sometimes used as an imitation. It is the same color but softer.

**OCCURRENCE.**—Material suitable for cutting is found in many localities: Urals, Australia, Chile, Arizona, California.

**SODALITE**, p. 500, mentioned as forming part of lapis lazuli, occurs also separately and is sometimes cut cabochon and has a limited use. In Bolivia it was used by the aborigines cut pearl shaped. It rarely has the fine blue lapis color.

**OCCURRENCE.**—In dense masses at Dungannon, Hastings County, Ont., Canada, and at Litchfield, Maine. In translucent material in Greenland, Siebenburgen and Vesuvius.

**FELDSPAR.**—Moonstone, Amazonite, Etc. Described on p. 488.

**COMPOSITION.**—The group is considered to consist of three distinct species and a number of intermediate "isomorphous mixtures."

|            |                                      |            |
|------------|--------------------------------------|------------|
| Orthoclase | $\text{KAlSi}_3\text{O}_8$           | Monoclinic |
| Albite     | $\text{NaAlSi}_3\text{O}_8$          | Triclinic  |
| Anorthite  | $\text{CaAl}_2\text{Si}_2\text{O}_8$ | Triclinic  |

Although constituting about one half of the known crust of the earth this group of great species only occasionally furnishes material suitable for jewelry.

**MOONSTONE.**

"Colorless, diffusing brilliant rays in a circle after the fashion of that luminary." The only variety valued in jewelry. Chiefly a variety of orthoclase, but also of albite or intermediate mixtures. The milky, bluish opalescence from which they take their name is caused by inclusions, which lie about perpendicular to one of the cleavages.

They are always cut more or less steeply en cabochon and go well as a border for large colored stones.

**OCCURRENCE.**—At the present day practically all the moonstones on the market come from the interior of Ceylon. Formerly many came from the St. Gothard district in Switzerland. Beautiful stones with blue opalescence come from California. Other localities are Amelia Court House, Va., Rio de Janeiro, Brazil, and West Australia. Albite moonstone is found at Media, Penn.

Peristerite is a less transparent variety from Macomb, N. Y., and Bathurst, Canada, which shows a pigeon blue opalescence.

**AMAZONITE OR AMAZON STONE.**—This is a green opaque variety of the potash feldspar microcline.

The most valued variety is apple green in color; the brighter green and the varieties with streaks and flecks of white yellow or red are of little worth.

The principal localities are in the Ilmen Mountains, Orenburg, Russia, Virginia, Pikes Peak, Col., and in North Carolina.

The name was given by Spaniards to some green mineral found among the Indians dwelling near the Amazon River. No occurrence of Amazon stone there, however,

has been found and there appears to have been some confusion with a jade or similar stone.

**SUNSTONE OR HELIOLITE.**—Sunstone is chiefly a variety of oligoclase, but also of albite and contains flakes of hematite or goethite which impart a spangled bronze appearance. The colors vary from grayish white to reddish gray, and the material resembles aventurine quartz and is sometimes called aventurine feldspar.

Bauer states that this variety of feldspar around 1800 was very rare and costly. Only a few specimens were known from one locality, Sattel Island in the White Sea.

It is now found in East India, Ceylon. The best sunstone is from Christiania fiord, Norway. Sunstone almost equal to the Norwegian is found at Media, Delaware County, Penn., and in Amelia Co., Va.

**LABRADORITE.**—The body color is usually a dull gray, but the "interference" colors which come and go as the stone is turned from side to side are usually broad flashes of blue and green, but also in yellow, red, pearl gray, orange, puce, amber, and peach-blossom hues. These colors are due both to a regular lamellar structure and to regularly placed microscopic inclusions.

The finest specimens are brought from the Isle of St. Paul off the coast of Labrador, but other localities yield beautiful material, Brisbane, Queensland, with a blue schiller; Djamo, Finland, a colorless labradorite, showing the interference colors in concentric circles.

**MALACHITE.**— $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$ . Described on p. 371. The green copper carbonate.

Although by the ancient Greeks and Romans the easily worked malachite was used as a gem, it is now only occasionally so used. The fine fibrous and stalactitic varieties are, however, used in large quantities, especially in Russia at Ekaterinenberg and Petrograd for the making of jewel cases, vases and even table tops and large columns. In general, however, the articles are only covered with a thin veneer of the malachite made from comparatively small pieces carefully built together like a mosaic.

**OCCURRENCE.**—The finest malachite is found in large masses at the copper mines of Nizhni Tagilsk in the Ural Mountains. It accompanies the copper ores in many parts of the world.

**CHLORASTROLITE OR ISLE ROYALE GREENSTONE**, from chloros (green), aster (star), and lithos (stone). Small rounded pebbles from Isle Royale, Lake Superior, which are opaque, of a mottled green color, somewhat chatoyant on the rounded sides, and take a high polish.

#### **AMBER.—Succinite Simeite.**

Amber is a fossil resin, derived from a now extinct variety of pine which lived during the Tertiary period. Its composition is: carbon, 78.96; hydrogen, 10.51; oxygen, 10.52. It consists mainly (85 to 90 per cent.) of a resin which resists all solvents.

**PROPERTIES.**—H., 2.5. Sp. gr., 1.065 to 1.081. Lustre resinous and very brilliant after polishing.

The color is yellow, sometimes reddish, brownish, and whitish, often clouded. The variety from Sicily, simeite, is brownish red

with a beautiful bluish to greenish fluorescence. Singly refracting, though often locally doubly refracting. Index about 1.54. *Negatively* electrified by friction.

While the Sicilian amber is fluorescent still commands a high price, the Prussian amber is sold by the pound and used for mouthpieces of pipes, cigar and cigarette-holders, umbrella handles and locally cut for cheap jewelry.

It formerly ranked very high, the Greeks obtained it from the Teutonic tribes and according to King, is entitled to "the highest antiquity in the list of precious stones used for personal ornament," since Homer mentions no gem except 'the gold necklace hung with bits of amber.'"

It is obtained now as for over 2,000 years chiefly from lignite-bearing sandstone along the coast of the Baltic from Danzig, West Prussia, to Memel, East Prussia. The most beautiful is obtained off shores of Catania, Sicily.

**JET.**—Jet is a compact, soft, light coal of a lustrous velvet black color, susceptible of a high polish.

The early Britons turned it on the lathe into rings, bracelets, anklets and later made it into scarf pins, bracelets, beads, etc., and in Whitby, Yorkshire, there is still a large industry amounting to about \$1,000,000 per year.

**OCCURRENCE.**—The finest specimens are now found in detached pieces in a clay near Whitby, Yorkshire, England. It also occurs in Germany, Colorado, South France, and Aragon, Spain.

**IMITATIONS.**—In this country it has been displaced by black-colored chalcedony. It is also imitated in gutta percha, glass, and obsidian.

**ANTHRACITE** is turned into compass cases, cups, saucers, vases, candlesticks and paperweights, and is carved by hand into a variety of small ornaments. Most of the anthracite is worked at Mountain Top, near Glen Summit, Lucerne County, Pa.

**RHODONITE.**— $\text{MnSiO}_3$ . Described on p. 271. The fine-grained massive variety is often cut into vases, paper weights, and in rounded stones for brooches, etc. It is very tough, takes a good polish and in color is a fine rose to dark red, often attractively veined with black.

The principal localities for cutting material are Cummington, Mass., and Ekaterinenberg, Urals.

**THULITE** is a beautiful rose to peach-blossom red variety of zoisite, itself an orthorhombic epidote. It owes its color to a little manganese and is essentially opaque.

Fine specimens come from Telemark, Norway, and Traversella, Piedmont.

**HEMATITE.**— $\text{Fe}_2\text{O}_3$ . Described on p. 271. The compact brilliant black variety of the great iron ore was used as a gem by the Babylonians and Egyptians and to this day it is made into beads, signet stones, bracelets, etc. When cut with a dull polish it is very similar to black pearl.

Other translucent or opaque stones occasionally cut are: thomsonite, lepidolite, fuchsite, hypersthene, lodestone, ilmenite, pyrite and rutile.



## PART IV.

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# DETERMINATIVE MINERALOGY.

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## CHAPTER XXII.

### TABLES FOR RAPID DETERMINATION OF THE COMMON MINERALS.

All schemes\* for determining minerals utilize essentially the same tests and differ principally in the order in which they are applied, the number of minerals considered and the completeness with which the minor or confirmatory tests are stated in the scheme or covered by a reference to the descriptions of the minerals.

The tables which follow are in the main an elaboration of the tables in the former editions, employing essentially the same classifying tests but differing in the following points:

1°. The results of the major tests are summed up in a "**KEY**" to 59 numbered groups.

2°. The number of species has been increased.

3°. The groups contain tabulations of confirmatory tests.

4°. In the thirty-five groups of minerals of non-metallic lustre alternative tables *A* and *B* are given, *A* the physical and chemical tests, *B* the tests upon crushed fragments with the polarizing microscope. The latter have proved their value during several years of use as auxiliary tables and are now incorporated.

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\* They may be said to vary between the von Kobell (Brush-Penfield) type in which "the tables have been so developed that tests for characteristic chemical constituents furnish the chief means of identification" (preface 1898 edition *Brush-Penfield Determinative Mineralogy*), and in which lustre, fusibility and tests for elements are the classifying tests, and the Weisbach-(Frazer-Brown) type, in which the purpose was "to help the determination of minerals by their physical characteristics" (preface *Weisbach's Tabellen*, first edition, 1866), and in which lustre, streak, color, sectility and hardness are the classifying tests.

In discussing this addition of microscopic tests to the ordinary mineral schemes the writer said,\* "schemes by which a student with a few months' experience 'determines' the identity of a larger or smaller series of the more common or important minerals rarely include the exact easily applied distinctions obtainable with the polarizing microscope, although this instrument is now in every mineralogical laboratory and in most well equipped chemical laboratories.

"If the polarizing microscope is to be used in such work the tests must be *quickly* obtainable and accurate. The thin sections of the petrographer will not therefore be available, nor in general can those optical characters be made prominent which are only obtainable for some particular direction of transmission of light. In my opinion also, for this particular kind of scheme, the optical characters should be made subordinate to the very thoroughly worked out so-called 'blowpipe tests' and 'physical tests.'"

### The Tests Leading to the Key.

In the tables which follow, the minerals are divided first into minerals of metallic lustre and minerals of non-metallic lustre (see p. 210).

The minerals of metallic lustre are sub-divided into twenty-four groups by the tests (or characters)

1. Color, see p. 211.
2. Streak, see p. 212.
3. Heating on charcoal, see p. 169.

The minerals of non-metallic lustre are divided into thirty-five groups by five tests.

1. "Taste" or Solubility in Water.—See p. 180. The test is valuable because the existence of a "taste" is unmistakable, but the recognition of the taste is not easy.

2. Solubility in Dilute Hydrochloric Acid.—See p. 180. This test fails only from carelessness.

3. Treatment on Charcoal with Soda.—This is Test II of page 197.

4. Treatment in Platinum Forceps.—This is the "fusion test." of pp. 164 and 165. The scheme and the safety of the forceps both require that the absence of volatile or easily fusible elements should first be proved on charcoal.

5. Flame Coloration.—See p. 165.

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\* Scheme for Utilizing the Polarizing Microscope in the Determination of Minerals of Non-Metallic Lustre, by A. J. Moses.

**The Minor Tests of the Groups 1-24 and 25A to 59A.**

The species are in order of hardness and characters of determinative value are in parallel columns.

Following each species is the number of the page on which it is described. *The determination must always be confirmed by reference to this description and, when possible, by comparison with known specimens.*

**The Tests\* of the Alternative Groups 25B to 29B.**

The tests recorded assume the use of crushed fragments but in the text descriptions of the species, especially in the silicates, special optical distinctions are given for thin sections, cleavages, etc.

**Crushing and Mounting** is described on p. 126. The thickness of the resultant grains is near the 0.03 to 0.04 mm. of well made thin sections.

**The Classifying Tests are:**

1. *The relative indices of refraction of the grains* and of four chosen mounting liquids.
2. *The birefringence of the grains* expressed in five terms determined by the interference colors.

**The Relative Indices of Refraction** are determined by "The Becke Test," p. 128, and "The van der Kolk Test," p. 129. The scheme considers only the indices of refraction corresponding to the two positions of extinction in the fragment.

The liquids used are:

|                                   | <i>Index at 15° C.</i> |
|-----------------------------------|------------------------|
| Xylol.....                        | 1.487                  |
| Bromoform.....                    | 1.590                  |
| $\alpha$ Monobrom-naphthalin..... | 1.655                  |
| Methylene Iodide.....             | 1.740                  |

**The Birefringence** is approximately determined in terms of interference colors as described on p. 137.

| <b>Interference Color.</b> | <b>Effect of Gypsum Red.</b>  | <b>Other Tests.</b>    |
|----------------------------|---|------------------------|
| BLACK                      | Red except at extinction positions.                                     | Unchanged by rotation. |
| GRAY OR WHITE              | Made yellow for crossed position, blue or purple for parallel position. |                        |
| BRIGHT A.                  | Made white or gray or black for crossed position.                       |                        |

|             |                                       |   |
|-------------|---------------------------------------|---|
| BRIGHT B.   | Bright colors for both positions.     | By mica plate notably different tints for crossed and parallel positions. |
| HIGH ORDER. | Indefinite colors for both positions. | Not noticeably affected by mica plate in either position.                 |

**Minor Tests. Upper Nicol Out.**

**Shape.\***—The self-explanatory terms "laths," "needles," "fibres," "triangles," "rhombs," "rectangles," and "irregular" are used. The term "plates" implies *flat* particles lacking straight edge boundaries.

**Color by Transmitted Light.**—If no color is given in the scheme, the fragments are colorless.

**Pleochroism.**—See p. 153.

**Minor Tests with Crossed Nicols.**

**Extinction and Extinction Angles.**—See p. 138.

The method of designating here used is:

Ex. || when the angle turned is zero.

Ex., Sym. when the angle turned is one-half the angle between two crystalline directions.

Ex., Obl. when the extinction is neither "parallel" nor "symmetrical," or the angle may be stated, *e. g.*, Ex. 27°.

**Elongation.**—In "laths," "needles," "fibres," etc., the longer direction or "Elongation" is usually a crystallographic direction. By the method p. 134 its "sign" may be determined as El., (+) or El., (−).

**Interference Figure.**—See pp. 140 to 145.

**The Optical Sign or Character.**—See p. 146.

**Precautions.**

1. The specimen should first be carefully studied with a hand glass. If it is one substance so far as this shows the testing may go on. If not fragments of the different substances must be obtained and separately tested.

2. If fine-grained or dull, crushed particles should be examined with the microscope as to homogeneity. The tests will be un-

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\* Crushing tends to develop the cleavages, and in a liquid the fragments tend to lie on the broadest cleavage surface, thus giving considerable constancy in shape for fragments of each mineral.

reliable if the material is impure, *unless the effect of the impurity upon the test is known.*

3. Lustres and colors should be observed on fresh fractures especially in minerals of metallic lustre.

4. Classifying tests must be decided; not weak, nor indefinite. If undecided, the species on both sides of the dividing line must be considered.

5. If as may happen the tests fit no species in the scheme or do fit some species the description of which is radically unlike the specimen, then either some error has been made or *the specimen belongs to a species not included in the scheme*, for which more elaborate tables will be needed.

#### CONVENTIONS AND ABBREVIATIONS.

The species in each group are printed in heavy type or ordinary type, according to their importance. The formula following is expected to suggest confirmatory blow-pipe tests. The page reference to the complete description of the species is also given. H., is hardness. Sp. gr., specific gravity.

**Systems of Crystallization** are indicated by the letters: I (isometric), T (tetragonal), O (orthorhombic), M (monoclinic), Tri (triclinic), H (hexagonal).

**Terms in Blowpipe Tests.** Soda for sodic carbonate, S. Ph. for salt of phosphorus, O. F. and R. F. for oxidizing and reducing flame, Co. Sol. for cobalt solution, coal for charcoal, Bi.Fl for Bismuth flux, Fl for flame, subl. for sublimate. The numbers under fusibility are the v. Kobell scale, p. 164. The "residue" means residue after fumes have ceased. *OT for open tube*  
*CT for closed tube*

#### **Terms in Optical Tests.**

Ex., " ; Ex., Obl.; Ex., 22°; Ex., Sym., denote that the extinction is respectively parallel, oblique, at angle of 22°, and symmetrical. El., (+); El., (-), denote that the elongation is (+) or (-). I. C. is for interference color, < for less than and > for greater than.

KEY.

I. MINERALS OF METALLIC OR SUBMETALLIC LUSTRE.\*

| The Color is                            | The Streak is | HEATED ON CHARCOAL YIELDS |                                   |                                    |  |  |                          |
|---|---------------|---------------------------|-----------------------------------|------------------------------------|--|--|--------------------------|
|   |               | Arsenical Odor.           | White Coating But no Garlic Odor. | Yellow Coating on Continued Blast. | Magnetic Residue, no Coating or Garlic Odor. | Non-Magnetic Metal, no Coating or Garlic Odor. | Not Previously included. |
| A. Black or Nearly                      | 1. Black      | 1                         | 2                                 | 3                                  | 4  | 5  | 6                        |
|   | 2. Not Black  |                           | 7                                 | 8                                  | 9  |  | 10                       |
| B. Silver-White, Tin White or Gray      | 1. Black      | 11                        | 12                                | 13                                 | 14   |  |                          |
|   | 2. Not Black  | 15                        | 16                                | 17                                 | 18   | 19   | 20                       |
| C. Yellow, Copper, Red, Bronze, or Blue | 1. Black      | 21                        |                                   |                                    | 22   |  |                          |
|   | 2. Not Black  |                           | 23                                |                                    |  | 24   |                          |

II. MINERALS OF NON-METALLIC LUSTRE.

| A. Minerals with Decided Taste   | Which Color the Flame.  | 25                       |              |                 |                |
|--|---|--------------------------|--------------|-----------------|----------------|
|  | Which do not Color the Flame.                                 | 26                       |              |                 |                |
|  |   | WITH HYDROCHLORIC ACID : |              |                 |                |
|  |   | Effer-vesces.            | Forms Jelly. | Dissolves only† | Is In-soluble. |
| B. Tasteless, but with Soda on Charcoal in the Reducing Flame Yields : | Arsenical Odor.   |                          |              | 27              | 28             |
|  | Fumes and a Metallic Globule.                                 | 29                       |              | 30              | 31             |
|  | Fumes but not a Metallic Globule                              | 32                       | 33           | 34              | 35             |
|  | No Fumes but Magnetic Residue.                                | 36                       |              | 37              |                |
| C. Neither A nor B but Heated in Pt. Forceps :                         | Fuses Easily to a White Glass or Enamel.                      | 38                       | 39           | 40              | 41             |
|  | Fuses Easily to a Colorless Glass.                            |                          | 42           | 43              | 44             |
|  | Fuses Easily to Colored Glass or Enamel.                      | 45                       | 46           | 47              | 48             |
|  | Fuses with More Difficulty than Common Orthoclase.            | 49                       | 50           | 51              | 52             |
|  | Is Infusible but in Powder Made Deep Blue by Cobalt Solution. |                          | 53           | 54              | 55             |
|  | Is Infusible, not Made Deep Blue by Cobalt Solution.          | 56                       | 57           | 58              | 59             |
|  |   |                          |              |                 |                |

\*Including dull black minerals with black streak.  
† or is decomposed.

# 1.

| Crystal System:<br>Name, Composition, Hardness and<br>Specific Gravity.  | On Coal in O. F. and R. F.   |  |                              | Other Tests.  | Solubility<br>(HCl Unless Specified).  | Tube Tests<br>(Closed Tube Unless<br>Specified O. T.).  |
|--|--|--|------------------------------|---|--|---|
|  | Sublimates and<br>Odors.   | Residue (Fumes<br>Caused).                           | Feasibility.                 |   |  |   |
| O. Enargite, p. 366, CuAsS <sub>4</sub><br>H., 3 Sp. gr., 4.4<br>I. Tennantite, p. 368, CuAsS <sub>7</sub><br>H., 3 to 4 Sp. gr., 4.6  | Volatile white.<br>As. SO <sub>2</sub><br>Volatile white.<br>As. SO <sub>2</sub>   | Metallic<br>Metallic                                 | I<br>I.5                     | Residue with HCl<br>azure blue Fl.<br>Like enargite.  | Sol. HNO <sub>3</sub><br>Sol. HNO <sub>3</sub>   | Yellow then red subl.<br>Like enargite.   |
| <b>2.</b>  |  |  |                              |   |  |   |
| O. Nagavagite, p. 400,<br>AuPb <sub>10</sub> Sb <sub>7</sub> TeS <sub>11</sub><br>H., 1.5 Sp. gr., 6.9 to 7.2<br>O. Stibnite, p. 334, Sb <sub>2</sub> S <sub>3</sub><br>H., 2 Sp. gr., 4.5 to 4.6  | Yellow and<br>white.<br>Dense white.<br>SO <sub>2</sub>  | Metallic<br>None                                     | I.5<br>I                     | Te reactions see p. 193.<br>One easy cleavage.<br>KOH partially dis-<br>solves. HCl gives<br>orange ppt.<br>Decomposed by KOH.<br>HCl gives orange ppt.<br>Residue with HCl<br>azure blue Fl. | Sol. HNO <sub>3</sub> white<br>ppt. with H <sub>2</sub> SO <sub>4</sub><br>Sol. (with odor<br>H <sub>2</sub> S)              | O.T. white subls. in<br>part fusible, in part<br>volatile.<br>Fuses. Subl. black hot,<br>red cold.                                |
| O. Stephanite, p. 389, Ag <sub>2</sub> SbS <sub>4</sub><br>H., 2 to 2.5 Sp. gr., 6.2 to 6.3<br>O. Polybasite, p. 390,<br>(Ag.Cu) <sub>8</sub> SbS <sub>8</sub><br>H., 2 to 3 Sp. gr., 6 to 6.2<br>—, Onofrite, p. 371, Hg(SSe)<br>H., 2.5 Sp. gr., 8 to 8.1<br>I. Tetrahedrite, p. 367, Cu <sub>8</sub> Sb <sub>7</sub> S <sub>7</sub><br>H., 3 to 4.5 Sp. gr., 4.5 to 5.1 | White, later<br>reddens. SO <sub>2</sub><br>Dense white,<br>later reddens.<br>SO <sub>2</sub><br>Lustrous. Se<br>Dense white.<br>SO <sub>2</sub> | Metallic<br>Metallic<br>Metallic<br>None<br>Metallic | I<br>I<br>Volatilizes<br>I.5 | Like enargite.  | Sol. HNO <sub>3</sub> (white<br>residue)<br>Sol. HNO <sub>3</sub> . (Ppt.<br>with HCl)<br>Insoluble<br>Sol. HNO <sub>3</sub> | Fuses. Slight red subl.<br>Fuses. No subl.<br>With soda gives glob-<br>ules of mercury.<br>Decrepitates. Fuses.<br>Dark red subl. |

# 3.

|   |  |          |   |   |                      |                              |
|---|--|----------|---|---|----------------------|------------------------------|
| I. Galenite, p. 318, PbS<br>H., 2.5 Sp. gr., 7.4 to 7.6 | White O. F.<br>Yellow R. F.<br>SO <sub>2</sub> | Metallic | 2 | With "Bismuth Flux,"<br>greenish yellow subl. | Sol. excess. hot HCl | Decrepitates. White<br>subl. |
|---|--|----------|---|---|----------------------|------------------------------|

# 4.

|   |              |                                   |          |  |  |                        |
|---|--------------|-----------------------------------|----------|--|--|------------------------|
| H. Ilmenite, p. 273, FeTiO <sub>3</sub><br>H., 5 to 6 Sp. gr., 4.5 to 5<br>I. Magnetite, p. 270, FeO <sub>4</sub><br>H., 5.5 to 6.5 Sp. gr., 4.9 to 5.2 | None<br>None | Magnetic<br>sometimes<br>Magnetic | 7<br>5.5 | S. Ph. bead. O. F. red.<br>R. F. violet.<br>Magnetic but loses<br>magnetism in O. F. | Sol. slowly (boiled<br>with tin is violet)<br>Soluble slowly | Unchanged<br>Unchanged |
|---|--------------|-----------------------------------|----------|--|--|------------------------|

# 5.

|  |                 |          |          |   |  |  |
|--|-----------------|----------|----------|---|--|--|
| I. Argentite, p. 386, Ag <sub>2</sub> S<br>H., 2 to 2.5 Sp. gr., 7.2 to 7.6  | SO <sub>2</sub> | Metallic | 1.5      | SECTILE. With soda, Ag and S<br>Emerald green fl. made azure blue by HCl<br>Residue with HCl gives azure blue fl. | Sol. HNO <sub>3</sub> . (Residue S. Ppt. with HCl)<br>Sol. HNO <sub>3</sub> (residue S)<br>Soluble | Fuses. No sublimate<br>Fuses. No subl. |
| O. Chalcocite, p. 364, Cu <sub>2</sub> S<br>H., 2.5 to 3 Sp. gr., 5.5 to 5.8 | SO <sub>2</sub> | Metallic | 2 to 2.5 |   |  |  |
| Tenorite, p. 369, CuO<br>H., 3 Sp. gr., 5.8 to 6.2                           | None            | Metallic | 3        |   |  |  |

# 6.

|  |                      |                      |                       |  |   |  |
|--|----------------------|----------------------|-----------------------|--|---|--|
| H. Graphite, p. 476, C<br>H., 1 to 2 Sp. gr., 2.1 to 2.2   | None                 | Slowly burned        | 7                     | In CuSO <sub>4</sub> solution with zinc <i>quickly</i> copper-plated. Marks paper gray<br>Colors borax amethystine in O. F. Marks paper black<br>Black color   | Insoluble   | Unchanged  |
| O. Pyrolusite, p. 281, MnO <sub>2</sub><br>H., 1 to 2.5 Sp. gr., 4.7 to 4.8  | None                 | Brown                | 7                     |  | Sol. HCl (evolution of Cl)<br>Insoluble   | Oxygen, often water  |
| I. Metacinnabarite, p. 376, HgS<br>H., 3 Sp. gr., 7.7 to 7.8<br>Coloradoite, p. 377, HgTe<br>H., 3 Sp. gr., 8.6<br>—, Psilomelane, p. 283, H <sub>2</sub> MnO <sub>4</sub><br>H., 5 to 6 Sp. gr., 4.5 to 5 | None<br>None<br>None | None<br>None<br>None | Volatilized<br>7<br>7 | Colors borax amethystine O. F. White ppt. with H <sub>2</sub> SO <sub>4</sub><br>Like pyrolusite but hard<br>Colors borax amethystine in O. F. Solutions yield a little jelly<br>High Sp. gr. Blue gray solutions with tin, p. 186 | Sol. HNO <sub>3</sub><br>Sol. HCl (evolution of Cl)<br>Sol. HCl (evolution of Cl)<br>Like pyrolusite<br>Sol. HCl (evolution of Cl)<br>Insoluble | With soda globules of Hg.<br>Globules of Hg and fusible subl.<br>Oxygen and water<br>Oxygen<br>A little water, no oxygen |
| Pollanite, p. 282, MnO <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 5<br>T. Braunitz, p. 280, MnO <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 4.7 to 4.8  |                      | Brown                | 7                     |  |   |  |
| O. Columbite, p. 355, Fe(CbTa) <sub>2</sub> O <sub>6</sub><br>H., 6 Sp. gr., 5.4 to 6.5  |                      |                      | 7                     |  |   |  |

# 7.

|   |   |          |   |                     |                                       |                           |
|---|---|----------|---|---------------------|---------------------------------------|---------------------------|
| H. Pyrrargyrite, p. 389, Ag <sub>2</sub> Sb <sub>2</sub> S<br>H., 2.5 Sp. gr., 5.7 to 5.8 | Dense white, later reddens. SO <sub>2</sub> | Metallic | 1 | Purplish-red streak | Sol. HNO <sub>3</sub> . White residue | Subl. black hot, red cold |
|---|---|----------|---|---------------------|---------------------------------------|---------------------------|



| On Cast in O. F. and R. F. |   |                  |                                   |                  | Other Tests   | Solubility<br>(HCl Unless Specified),                      | Tube Tests<br>(Classified Unless<br>Specified O. F.), |
|----------------------------|---|------------------|-----------------------------------|------------------|---|--|---|
| Mineral                    | Formula   | Color and Lustre | Reaction to Heat                  | Reaction to Cold |   |  |   |
| 8.                         |   |                  |                                   |                  |   |  |   |
| 1. Uraninite, p. 343       | Uranyl Uranate                                      | From impurities  |                                   |                  |   |  |   |
| H., 5-5                    | Sp. gr., 9 to 9.7                                   |                  |                                   |                  | For radioactivity see page 195                              | Sol. HNO <sub>3</sub> . Yel-<br>low ppt. with am-<br>monia |   |
| 9.                         |   |                  |                                   |                  |   |  |   |
| 1. Limonite, p. 274.       | Fe(OH) <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub> | None             | Magnetic                          | 5 to 5.5         | Yellowish brown streak<br>often reacts for Mn.              | Soluble  | Reddens. Yields much<br>water                         |
| H., 5 to 5.5               | Sp. gr., 3.6 to 4                                   |                  |                                   |                  |   |  |   |
| 2. Turquoise, p. 274.      | Fe <sub>2</sub> O <sub>3</sub> (OH) <sub>3</sub>    | None             | Magnetic                          | 5 to 5.5         | Reddish brown streak  |  | Decrepitates. Yields<br>water                         |
| H., 5 to 6                 | Sp. gr., 4.3 to 4.5                                 |                  |                                   |                  |   |  |   |
| 3. Goethite, p. 273.       | Fe(OH)  | None             | Magnetic<br>slag                  | 5 to 5.5         | CRYSTALS. Yellowish<br>brown streak often<br>reacts for Mn. | Soluble  | Reddens. Yields water                                 |
| H., 5 to 5.5               | Sp. gr., 4 to 4.4                                   |                  |                                   |                  |   |  |   |
| 4. Wolframite, p. 352.     | (FeMn)WO <sub>4</sub>                               | None             | Magnetic<br>(crystalline<br>bead) | 3 to 4           | High sp. gr. Blue<br>solutions with tin, see<br>p. 194      | Partially soluble  |   |
| H., 5 to 5.5               | Sp. gr., 7.1 to 7.5                                 |                  |                                   |                  |   |  |   |
| 5. Ilmenite, p. 273.       | FeTiO <sub>3</sub>                                  | None             | Sometimes<br>magnetic             | 7                | Filtered solution boiled<br>with tin becomes<br>violet      | Partially soluble  | Unchanged   |
| H., 5 to 6                 | Sp. gr., 4.5 to 5                                   |                  |                                   |                  |   |  |   |
| 6. Hematite, p. 271.       | Fe <sub>2</sub> O <sub>3</sub>                      | None             | Magnetic                          | 7                | Reddish brown streak  | Soluble  | No water  |
| H., 5.5 to 6.5             | Sp. gr., 4.9 to 5.3                                 |                  |                                   |                  |   |  |   |

# 10.

|   |                                      |   |                                      |   |  |  |
|---|--------------------------------------|---|--------------------------------------|---|--|--|
| I. Alabandite, p. 280, MnS<br>H., 3.5 to 4 Sp. gr., 3.9 to 4<br>T. Hausmannite, p. 281, Mn <sub>2</sub> O <sub>4</sub><br>H., 5 to 5.5 Sp. gr., 4.7 to 4.8<br>O. Manganite, p. 282, MnO(OH)<br>H., 5 to 6 Sp. gr., 3.7 to 4.7<br>I. Uraninite, p. 243, UO <sub>2</sub> , UO <sub>3</sub> , etc.<br>H., 5.5 Sp. gr., 9 to 9.7          | None<br>None<br>None<br>None<br>None | Brown<br>Unchanged<br>Unchanged<br>Unchanged<br>Unchanged     | 3<br>7<br>7<br>6 to 7<br>7<br>7<br>7 | Cubic cleavage. Green streak<br>Twinned pyramids.<br>Streak chestnut brown<br>Dark brown streak.<br>Prismatic crystals<br>Pitch-like lustre. High sp. gr.<br>Dark brown streak.<br>Green beads with borax or S. Ph.<br>See p. 186<br>Like rutile<br>Violet S. Ph. bead in R. F. | Effervesces odor of H <sub>2</sub> S<br>Sol. HCl. (Evolves Cl)<br>Sol. HCl. (Evolves Cl)<br>Sol. HNO <sub>3</sub> or H <sub>2</sub> SO <sub>4</sub> gives yellow ppt. with ammonia<br>Insoluble<br>Insoluble<br>Insoluble<br>Insoluble | Very slight yellow<br>No oxygen<br>Much water. A little oxygen<br>Unchanged<br>Unchanged<br>Unchanged<br>Unchanged |
| I. Chromite, p. 346, FeCr <sub>2</sub> O <sub>4</sub><br>H., 5.5 Sp. gr., 4.3 to 4.6<br>O. Columbite, p. 355, Fe(CbTa) <sub>2</sub> O <sub>4</sub><br>H., 6 Sp. gr., 5.4 to 6.5<br>O. Brookite, p. 310, TiO <sub>2</sub><br>H., 5.5 to 6 Sp. gr., 3.9 to 4<br>T. Rutile, p. 309, TiO <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 4.1 to 4.2 | None<br>None<br>None<br>None<br>None | Unchanged<br>Unchanged<br>Unchanged<br>Unchanged<br>Unchanged | 7<br>7<br>7<br>7<br>7                |   |  |  |

# 11.

|  |   |  |                              |   |   |  |
|--|---|--|------------------------------|---|---|--|
| O. Lollingite, p. 331, FeAs<br>H., 5 to 5.5 Sp. gr., 7 to 7.4<br>I. Cobaltite, p. 290, CoAsS<br>H., 5.5 Sp. gr., 6 to 6.1<br>I. Smaltite, p. 291, (Co,Ni)As<br>H., 5 to 6 Sp. gr., 6.4 to 6.6<br>O. Arsenopyrite, p. 330, FeAsS<br>H., 5.5 to 6 Sp. gr., 6 to 6.2<br>I. Sperryite, p. 405, PtAs <sub>2</sub><br>H., 6 to 7 Sp. gr., 10.6 | Vol. white.<br>As.<br>Vol. white.<br>As. SO <sub>3</sub><br>Vol. white.<br>As<br>Vol. white.<br>As. SO <sub>3</sub><br>Slight vol. white.<br>As | Magnetic<br>Magnetic<br>Magnetic<br>Magnetic<br>Metallic | 2<br>2 to 3<br>2.5<br>2<br>2 | Borax bead deep blue O. F. and R. F.<br>Like cobaltite. Often with erythrite<br>After ignition Sol., with odor of H <sub>2</sub> S, and yellow ppt. | Sol. HNO <sub>3</sub> (red with white residue)<br>Sol. HNO <sub>3</sub> (red to green)<br>Sol. HNO <sub>3</sub> (suphur residue)<br>Insoluble | Mirror and black subl.<br>C. T. unaltered. O. T. As and SO <sub>3</sub><br>Mirror and black subl.<br>Brownish red subl. Later mirror and black<br>O. T. spongy platinum and white ubl. |
|--|---|--|------------------------------|---|---|--|

| Crystal System:<br>Name, Composition, Hardness and<br>Specific Gravity.                                  | On Coal in O. F. and R. F.                          |                            |             | Other Tests.   | Solubility<br>(HCl Unless Specified).       | Tube Tests<br>(Closed Tube Unless<br>Specified O. F.). |
|--|---|----------------------------|-------------|--|---|--|
|  | Sublimates and<br>Odors.                            | Residue (Fumes<br>Ceased). | Fusibility. |  |   |  |
| I. Sphalerite, p. 298, ZnS<br>H., 3.5 to 4 Sp. gr., 3.9 to 4.1   | Yellow hot<br>White cold.<br>SO <sub>2</sub>        | None                       | 5           | Light brown streak.<br>Subl. bright green<br>with Co. Sol.   | Effervesces. Gives<br>odor H <sub>2</sub> S | No sublimate   |
| I. Franklinite, p. 302.<br>(FeMnZn)O(FeMn) <sub>2</sub> O <sub>3</sub><br>H., 6 to 6.5 Sp. gr., 5 to 5.2 | Slight white  | Magnetic                   | 7           | Dark brown streak.<br>Soda bead O. F.<br>bluish green. Subl.<br>Pale streak. with soda bluish<br>green with Co. Sol. | Slowly in HCl<br>evolving Cl                | Unchanged  |
| T. Cassiterite, p. 307, SnO <sub>2</sub><br>H., 6 to 7 Sp. gr., 6.8 to 7.1                               | Some varieties<br>give yellow<br>hot, white<br>cold |                            | 7           |  | Insoluble                                   | Unchanged  |

## 8.

|   |                 |   |                                   |  |
|---|-----------------|---|-----------------------------------|--|
| I. Uraninite, p. 343<br>Uranyl Uranate<br>H., 5.5 Sp. gr., 9 to 9.7 | From impurities | 7 | For radioactivity see<br>page 195 | Sol. HNO <sub>3</sub> . Yel-<br>low ppt. with am-<br>monia |
|---|-----------------|---|-----------------------------------|--|

## 9.

|  |      |                                   |          |   |                   |                               |
|--|------|-----------------------------------|----------|---|-------------------|-------------------------------|
| — Limonite, p. 274.<br>Fe(OH) <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub><br>H., 5 to 5.5 Sp. gr., 3.6 to 4 | None | Magnetic                          | 5 to 5.5 | Yellowish brown streak<br>often reacts for Mn.              | Soluble           | Reddens. Yields much<br>water |
| — Turquoise, p. 274, FeO <sub>4</sub> (OH) <sub>2</sub><br>H., 5 to 6 Sp. gr., 4.3 to 4.5                    | None | Magnetic                          | 5 to 5.5 | Reddish brown streak  |                   | Decrepitates. Yields<br>water |
| O. Goethite, p. 273, FeO(OH)<br>H., 5 to 5.5 Sp. gr., 4 to 4.4   | None | Magnetic<br>slag                  | 5 to 5.5 | Crystals. Yellowish<br>brown streak often<br>reacts for Mn. | Soluble           | Reddens. Yields water         |
| M. Wolframite, p. 352.<br>(FeMn)WO <sub>4</sub><br>H., 5 to 5.5 Sp. gr., 7.1 to 7.5                          | None | Magnetic<br>(crystalline<br>bead) | 3 to 4   | High sp. gr. Blue<br>solutions with tin, see<br>p. 194      | Partially soluble |                               |
| H. Ilmenite, p. 273, FeTiO <sub>3</sub><br>H., 5 to 6 Sp. gr., 4.5 to 5                                      | None | Sometimes<br>magnetic             | 7        | Filtered solution boiled<br>with tin becomes<br>violet      | Partially soluble | Unchanged                     |
| H. Hematite, p. 271, Fe <sub>2</sub> O <sub>3</sub><br>H., 5.5 to 6.5 Sp. gr., 4.9 to 5.3                    | None | Magnetic                          | 7        | Reddish brown streak  | Soluble           | No water                      |

# 10.

|  |                              |  |                       |   |   |  |
|--|------------------------------|--|-----------------------|---|---|--|
| I. Alabandite, p. 280. MnS<br>H., 3.5 to 4 Sp. gr., 3.9 to 4<br>T. Hausmannite, p. 281. Mn <sub>2</sub> O <sub>4</sub><br>H., 5 to 5.5 Sp. gr., 4.7 to 4.8<br>O. Manganite, p. 282. MnO(OH)<br>H., 5 to 6 Sp. gr., 3.7 to 4.7<br>I. Uraninite, p. 243. UO <sub>2</sub> , UO <sub>3</sub> , etc.<br>H., 5.5 Sp. gr., 9 to 9.7 | None<br>None<br>None<br>None | Brown<br>Unchanged<br>Unchanged<br>Unchanged     | 3<br>7<br>7<br>6 to 7 | Cubic cleavage. Green streak<br>Twinned pyramids.<br>Streak chestnut brown<br>Dark brown streak.<br>Prismatic crystals<br>Pitch-like lustre. High sp. gr. | Effervesces odor of H <sub>2</sub> S<br>Sol. HCl. (Evolves Cl)<br>Sol. HCl. (Evolves Cl)<br>Sol. HNO <sub>3</sub> or H <sub>2</sub> SO <sub>4</sub> gives yellow ppt. with ammonia<br>Insoluble | Very slight yellow<br>No oxygen<br>Much water. A little oxygen<br>Unchanged<br>Unchanged<br>Unchanged<br>Unchanged |
| Chromite, p. 346. FeCr <sub>2</sub> O <sub>4</sub><br>5.5 Sp. gr., 4.3 to 4.6<br>Columbite, p. 355.<br>Fe(CbTa)O <sub>4</sub><br>6 Sp. gr., 5.4 to 6.5<br>Brookite, p. 310. TiO <sub>2</sub><br>5.5 to 6 Sp. gr., 3.9 to 4<br>Rutile, p. 300. TiO <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 4.1 to 4.2                           | None<br>None<br>None<br>None | Unchanged<br>Unchanged<br>Unchanged<br>Unchanged | 7<br>7<br>7<br>7      | Dark brown streak.<br>Green beads with borax or S. Ph.<br>See p. 186<br>Like rutile<br>Violet S. Ph. bead in R. F.  | Insoluble<br>Insoluble<br>Insoluble<br>Insoluble  | Unchanged<br>Unchanged<br>Unchanged<br>Unchanged   |

# 11.

|   |   |  |                              |  |   |   |
|---|---|--|------------------------------|--|---|---|
| O. Lollingite, p. 331. FeAs<br>H., 5 to 5.5 Sp. gr., 7 to 7.4<br>I. Cobaltite, p. 290. CoAsS<br>H., 5.5 Sp. gr., 6 to 6.1<br>I. Smaltite, p. 291. (Co,Ni)As<br>H., 5 to 6 Sp. gr., 6.4 to 6.6<br>O. Arsenopyrite, p. 330. FeAsS<br>H., 5.5 to 6 Sp. gr., 6 to 6.2<br>I. Sperryite, p. 405. PrAs<br>H., 6 to 7 Sp. gr., 10.6 | Vol. white.<br>As.<br>Vol. white.<br>As. SO <sub>3</sub><br>Vol. white.<br>As<br>Vol. white.<br>As. SO <sub>3</sub><br>Slight vol. white.<br>As | Magnetic<br>Magnetic<br>Magnetic<br>Magnetic<br>Metallic | 2<br>2 to 3<br>2.5<br>2<br>2 | Borax bead deep blue<br>O. F. and R. F.<br>Like cobaltite. Often with erythrite<br>After ignition Sol., with odor of H <sub>2</sub> S, and yellow ppt. | Sol. HNO <sub>3</sub> (red with white residue)<br>Sol. HNO <sub>3</sub> (red to green)<br>Sol. HNO <sub>3</sub> (suphur residue)<br>Insoluble | Mirror and black subl.<br>C. T. unaltered. O. T. As and SO <sub>3</sub><br>Mirror and black subl.<br>Brownish red subl.<br>Later mirror and black<br>O. T. spongy platinum and white ubl. |
|---|---|--|------------------------------|--|---|---|

## 12.

| Name, Composition, Hardness and Specific Gravity.                               | On Coal in O. F. and R. F.             |                         |             | Other Tests.   | Solubility (HCl Unless Specified).   | Tube Tests (Closed Tube Unless Specified O. T.). |
|---|--|-------------------------|-------------|--|--------------------------------------|--|
|   | Sublimates and Odors.                  | Residue (Fumes Ceased). | Fusibility. |  |                                      |  |
| O. Stibnite, p. 334, Sb <sub>2</sub> S <sub>3</sub><br>H., 2 Sp. gr., 4.5       | Dense white, volatile. SO <sub>2</sub> | None if pure            | 1           | Solution reppd. orange by H <sub>2</sub> S from dissolving portion | Sol. HCl hot (odor H <sub>2</sub> S) | Fuses. Subl. black hot, brown red cold           |
| I. Tiemannite, p. 377, HgSe<br>H., 2.5 Sp. gr., 8.9                             | Lustrous. Se                           | None                    | Volatile    | Open tube Se odor and fusible subl.                                |                                      | Gray subl. With soda mercury globules            |
| O. Famatinite, p. 367, CuSbS <sub>4</sub><br>H., 3.5 Sp. Gr., 4.5               | White volatile. SO <sub>2</sub>        | Metallic                | 1 to 1.5    | Tinge of copper red  | Soluble HNO <sub>3</sub>             | Decrepitates S. subl. and some dark red          |
| I. Tetrahedrite, p. 367, CuSbS <sub>4</sub><br>H., 3 to 4.5 Sp. gr., 4.5 to 5.1 | Dense white volatile. SO <sub>2</sub>  | Metallic                | 1.5         | Residue with HCl azure blue fl.                                    | Sol. HNO <sub>3</sub>                | Fuses. Dark-red sublimate                        |
| I. Stannite, p. 306, (Cu, Sn, Fe)S<br>H., 4 Sp. gr., 4.5                        | Non-volatile white. SO <sub>2</sub>    | Slightly magnetic       | 1.5         | Subl. bluish green with Co. Sol.                                   | Sol. HNO <sub>3</sub> white residue  | Decrepitates. Faint subl.                        |

## 13.

|  |   |              |   |   |                                     |                           |
|--|---|--------------|---|---|-------------------------------------|---------------------------|
| I. Galenite, p. 318, PbS<br>H., 2.5 Sp. gr., 7.4 to 7.6                | White O. F. Yellow R. F. SO <sub>2</sub>      | None if pure | 2 | Greenish yellow subl. with Bi. Fl. cubic cleavage | Sol. HCl hot. (Crystals on cooling) | Decrepitates. Faint subl. |
| O. Jamesonite, p. 320, PbSbS <sub>4</sub><br>H., 2.5 Sp. gr., 5.5 to 6 | Dense white vol. Some yellow. SO <sub>2</sub> | None if pure | 1 | Like galenite. Often felted or hair like          | Sol. (with odor H <sub>2</sub> S)   | Subl. brownish red cold   |
| I. Clausthalite, p. 321, PbSe<br>H., 2.5 to 3 Sp. gr., 7.8 to 8.5      | Gray then yellow. Se                          | None if pure | 2 | Odor of Se.                                       |                                     | O. T. red subl.           |

## 14.

|   |                 |          |   |                                 |  |                                      |
|---|-----------------|----------|---|---------------------------------|--|--------------------------------------|
| I. Linnaeite, p. 289, (Co, Ni) <sub>3</sub> S <sub>4</sub><br>H., 5.5 Sp. gr., 4.8 to 5 | SO <sub>2</sub> | Magnetic | 2 | Borax deep blue O. F. and R. F. | Sol. HNO <sub>3</sub> red with sulphur residue | Slight yellow subl. with strong heat |
|---|-----------------|----------|---|---------------------------------|--|--------------------------------------|

## 15.

|   |                                 |          |             |                                     |                                       |                                  |
|---|---------------------------------|----------|-------------|-------------------------------------|---------------------------------------|----------------------------------|
| Antimony, p. 333, Sb<br>H., 3 to 3.5 Sp. gr., 6.5 to 6.7                        | Dense white, volatile           | None     | 1           | Burns with yellow-green fl. Brittle | Soluble                               | O. T. white crystals             |
| H. Arsenic, p. 329, As<br>H., 3.5 Sp. gr., 5.6 to 5.7                           | Volatile white. As              | None     | Volatilizes | Burns with light-blue fl.           | Sol. HNO <sub>3</sub>                 | Mirror and black subl.           |
| I. Tetrahedrite, p. 367, CuSbS <sub>4</sub><br>H., 3 to 4.5 Sp. gr., 4.5 to 5.1 | White volatile. SO <sub>2</sub> | Metallic | 1.5         | Residue with HCl azure blue fl.     | Sol. HNO <sub>3</sub> (white residue) | Decrepitates. Brownish red subl. |

# 16.

|  |   |                 |   |   |   |   |
|--|---|-----------------|---|---|---|---|
| H. Molybdenite, p. 349, MoS <sub>2</sub><br>H., 1 to 1.5 Sp. gr., 4.6 to 4.9           | Slight white and bronze.<br>SO <sub>4</sub> | Bronzed         | 7 | Yellowish green<br>Marks paper  | Sol. conc. HNO <sub>3</sub><br>(luminous)           | O. T. SO <sub>2</sub> and yellow crystals |
| Gold Telluride, p. 400,<br>(Au, Ag)Te <sub>2</sub><br>H., 1.5 to 2.5 Sp. gr., 7.9 to 9 | Grayish white                               | Metallic yellow | 1 | Warmed in test tube with conc. H <sub>2</sub> SO <sub>4</sub> is violet | Sol. HNO <sub>3</sub>                               | O. T. white fusible subl.                 |
| I. Hesseite, p. 387, AgTe<br>H., 2 to 2.5 Sp. gr., 8.3 to 8.6                          | Slight gray                                 | Metallic        | 1 | Like gold telluride   | Sol. HNO <sub>3</sub>                               | O. T. white fusible subl.                 |
| H. Tellurium, p. 465, Te with Se.S<br>H., 2 to 2.5 Sp. gr., 6.1 to 6.3                 | Slight gray                                 | None            | 1 | Like gold telluride   | Violet solution with H <sub>2</sub> SO <sub>4</sub> | O. T. white fusible subl.                 |

# 17.

|  |                                   |              |     |  |   |                              |
|--|-----------------------------------|--------------|-----|--|---|------------------------------|
| H. Tetradymite, p. 326,<br>Bi <sub>2</sub> (Te,S) <sub>2</sub><br>H., 1.5 to 2 Sp. gr., 7.2 to 7.6 | Yellow and white                  | None         | 1.5 | Basal cleavage. Also like bismuth                    |   | O. T. white fusible subl.    |
| H. Bismuth, p. 326, Bi<br>H., 2 to 2.5 Sp. gr., 9.7 to 9.8   | Yellow and white                  | None if pure | 1   | Chocolate brown and red subl. with Bi.Fl. on plaster | Sol. HNO <sub>3</sub> (white ppt. by water) |                              |
| O. Bismuthinite, p. 326, Bi <sub>2</sub> S <sub>3</sub><br>H., 2.5 to 3.5 Sp. gr., 6.4 to 7        | Yellow and white. SO <sub>2</sub> | None         | 1   | Like bismuth   | Like bismuth                                | O. T. SO <sub>2</sub> odor   |
| O. Bournonite, p. 319, CuPbSbS <sub>2</sub><br>H., 2.5 to 3 Sp. gr., 5.7 to 5.9                    | Yellow and white. SO <sub>4</sub> | Metallic     | 1   | Green-yellow subl. and green Fl. with Bi.Fl.         | Blue solution HNO <sub>3</sub> white ppt.   | Dark red subl. De-crepitates |

# 18.

|   |      |                    |   |                                     |                          |           |
|---|------|--------------------|---|-------------------------------------|--------------------------|-----------|
| I. Platinum, p. 405, Pt(Fe)<br>H., 4 to 4.5 Sp. gr., 14 to 19 | None | Magnetic sometimes | 7 | Malleable                           | Sol. aqua regia only     | Unchanged |
| I. Iron, p. 265, Fe<br>H., 4 to 5 Sp. gr., 7.3 to 7.8         |      | Magnetic           | 7 | Magnetic without heating. Malleable | Soluble HNO <sub>3</sub> |           |

# 19.

|  |                 |                 |     |   |   |                     |
|--|-----------------|-----------------|-----|---|---|---------------------|
| I. Silver, p. 385, Ag<br>H., 2.5 to 3 Sp. gr., 10.1 to 11.1                      |                 | Bright metallic | 2   | Solutions plate copper and give curdy ppt. with HCl | Sol. HNO <sub>3</sub> or H <sub>2</sub> SO <sub>4</sub> |                     |
| O. Stromeeyerite, p. 387,<br>(Ag,Cu) <sub>2</sub> S<br>H., 2.5 to 3 Sp. gr., 6.2 | SO <sub>2</sub> | Metallic        | 1.5 | Residue blue Fl. with HCl                           | Sol. HNO <sub>3</sub>                                   | Fuses. No sublimate |
| I. Amalgam, p. 386, AgHg<br>H., 3 to 3.5 Sp. gr., 13.7 to 14.1                   |                 | Metallic silver |     | Rubbed on copper gives silver color                 | Sol. HNO <sub>3</sub>                                   | Globules of mercury |

| Name, Composition, Hardness and Specific Gravity.           | On Coal in O. F. and R. F. |                             |             | Other Tests.   | Solubility (HCl Unless Specified).  | Tube Tests (Closed Tube Unless Specified O. T.).   |
|---|----------------------------|-----------------------------|-------------|--|-------------------------------------|--|
|   | Sublimates and Odors.      | Residue (Fumes Ceased).     | Fusibility. |  |                                     |  |
| <b>I. Platinum, p. 405. Pt</b>                              | None                       | Magnetic                    | 7           | Malleable, often magnetic                                  | Soluble aqua regia<br>Insoluble     | Unchanged<br>O. T. odor of Os, pungent, unpleasant |
| H., 4 to 4.5 Sp. gr., 14 to 19                              |                            |                             |             |  |                                     |  |
| H. Iridosmine, p. 406, (Ir.Os)                              | Os                         | Metallic                    | 7           |  |                                     |  |
| H., 6 to 7 Sp. gr., 19 to 21                                |                            |                             |             |  |                                     |  |
| <b>20.</b>  |                            |                             |             |  |                                     |  |
| Mercury, p. 375. Hg   |                            | None                        | Volatilizes | With Bi.Fl. on plaster, volatile, scarlet and yellow subl. | Sol. HNO <sub>3</sub>               | Subl. of small metallic globules                   |
| H., — Sp. gr., 13.6   |                            |                             |             |  |                                     |  |
| <b>21.</b>  |                            |                             |             |  |                                     |  |
| H. Niccolite, p. 203. NiAs                                  | Volatile white. As         | Magnetic                    | 2           | See page 191; copper color                                 | Partial                             | Mirror subl.                                       |
| H., 5 to 5.5 Sp. gr., 7.2 to 7.7                            |                            |                             |             |  |                                     |  |
| <b>22.</b>  |                            |                             |             |  |                                     |  |
| H. Covellite, p. 363, CuS                                   | SO <sub>2</sub>            | Metallic                    | 2.5 (burns) | Burns with blue Fl. Indigo blue color                      | Sol. slowly                         | Fusible subl. red hot, yellow cold                 |
| H., 1.5 to 2 Sp. gr., 4.6                                   |                            |                             |             |  |                                     |  |
| I. Bornite, p. 364, Cu <sub>5</sub> FeS <sub>4</sub>        | SO <sub>2</sub>            | Magnetic (red if broken)    | 2.5         | Red-bronze fracture. With HCl blue Fl.                     | Sol. HNO <sub>3</sub> (residue S)   | Blackens   |
| H., 3 Sp. gr., 4.9 to 5.4                                   |                            |                             |             |  |                                     |  |
| H. Millerite, p. 202, NiS                                   | SO <sub>2</sub>            | Magnetic                    | 1.5 to 2    | Colors borax O. F. red hot, brown cold                     | Sol. aqua regia                     | S on intense heating                               |
| H., 3 to 3.5 Sp. gr., 5.3 to 5.6                            |                            |                             |             | Needles or hair  |                                     |  |
| T. Chalcocopyrite, p. 365, Cu <sub>2</sub> FeS <sub>2</sub> | SO <sub>2</sub>            | Magnetic (gray if broken)   | 2 to 2.5    | Like bornite except deep brassy-yellow                     | Sol. HNO <sub>3</sub> (residue S)   | Darkens, may give yellow subl.                     |
| H., 3.5 to 4.1 Sp. gr., 4.1 to 4.3                          |                            |                             |             |  |                                     |  |
| I. Pentlandite, p. 202, (Fe,Ni)S                            | SO <sub>2</sub>            | Magnetic (yellow if broken) | 1.5 to 2    | Light bronze-yellow on fracture. Cleavage octahedral       |                                     |  |
| H., 3.5 to 4 Sp. gr., 4.6 to 5                              |                            |                             |             | Bronze-yellow. Slightly magnetic before fusion             | Effervesces (odor H <sub>2</sub> S) | A little S (yellow, fusible)                       |
| H. Pyrrhotite, p. 266, Fe <sub>7</sub> S <sub>8+11</sub>    | SO <sub>2</sub>            | Magnetic                    | 2.5 to 3    |  |                                     |  |
| H., 3.5 to 4.5 Sp. gr., 4.5 to 4.6                          |                            |                             |             |  |                                     |  |

|   |                 |                             |             |  |  |                                    |
|---|-----------------|-----------------------------|-------------|--|--|------------------------------------|
| <b>I. Pyrite</b> , p. 266, FeS <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 4.9 to 5.2 | SO <sub>2</sub> | Magnetic                    | 2.5 (burns) | Pale brass. <i>Completely</i> sol. in fine powder in strong HNO <sub>3</sub><br>Like pyrite but less soluble in HNO <sub>3</sub> | Sol. HNO <sub>3</sub>                            | Fusible subl. red hot, yellow cold |
|   | SO <sub>2</sub> | Magnetic                    | 2.5 (burns) |  | Sol. HNO <sub>3</sub> (residue S)                | Fusible subl. red hot, yellow cold |
| <b>23.</b>  |                 |                             |             |  |  |                                    |
| <b>O. Gold Telluride</b> , p. 400.<br>H., 1.5 to 2.5 Sp. gr., 8.3 to 8.6.       | Grayish white   | Metallic yellow             | 1           | Warmed in test tube with conc. H <sub>2</sub> SO <sub>4</sub> is violet  | Sol. HNO <sub>3</sub>                            | O. T. White fusible subl.          |
|   |                 |                             |             |  |  |                                    |
| <b>24.</b>  |                 |                             |             |  |  |                                    |
| <b>I. Gold</b> , p. 399. Au<br>H., 2.5 to 3 Sp. gr., 19.3                       |                 | Metallic yellow<br>Metallic | 2.5<br>3    | The golden yellow streak and color<br>Fused mass red, with HCl azure blue fl.  | Sol. aqua regia<br>Sol. HNO <sub>3</sub> (green) |                                    |
|   |                 |                             |             |  |  |                                    |
| <b>I. Copper</b> , p. 362, Cu<br>H., 2.5 to 3 Sp. gr., 8.8 to 8.9               |                 |                             |             |  |  |                                    |



## 25. A.

| Crystal System : Name, Composition, Hardness, and Specific Gravity. |  | Taste.                | On Charcoal.  | Closed Tube.                          |
|---|--|-----------------------|---|---------------------------------------|
| 1. FLAME YELLOW.<br>ABSORBED BY<br>"COLOR SCREEN"                   | H. Soda Nitre, p. 427.<br>NaNO <sub>3</sub>  | Cooling               | F. = 1. Deflagrates                                       | With KHSO <sub>4</sub><br>brown vapor |
|   | H., 1.5 to 2 Sp. gr., 2.2  |                       |   |                                       |
|   | M. Mirabilite, p. 426.<br>Na <sub>2</sub> SO <sub>4</sub> + 10H <sub>2</sub> O           | Bitter                | F. = 1.5 and will<br>stain silver                         | Water                                 |
|   | H., 1.5 to 2 Sp. gr., 1.5  |                       |   |                                       |
|   | I. Halite, p. 425, NaCl  | Salty                 | F. = 1.5  | A little water                        |
|   | H., 2.5 Sp. gr., 2 to 2.6  |                       |   |                                       |
| 2. FLAME VIOLET<br>THROUGH COLOR<br>SCREEN                          | M. Trona, p. 427.<br>NaCO <sub>3</sub> NaHCO <sub>3</sub> · 2 H <sub>2</sub> O           | Alkaline              | F. = 1  | Water                                 |
|   | H., 2.5 to 3 Sp. gr., 2.1  |                       |   |                                       |
|   | O. Carnallite, p. 420.<br>KCl · MgCl <sub>2</sub> · 6 H <sub>2</sub> O                   | Salty and<br>bitter   | F. = 1 to 1.5. Ig-<br>nited with Co. sol.<br>pink         | Much water                            |
|   | H., 1 Sp. gr., 1.6   |                       |   |                                       |
|   | O. Nitre, p. 420, KNO <sub>3</sub>   | Salty and<br>cooling  | F. = 1. Deflagrates                                       | With KHSO <sub>4</sub><br>brown vapor |
|   | H., 2 Sp. gr., 2.1   | Astringent            | F. = 1. Swells,<br>froths, will stain<br>silver           | Much water,<br>acid at high<br>heat   |
| 3. FLAME<br>GREEN   | I. Kalinite, p. 420.<br>KAl(SO <sub>4</sub> ) <sub>2</sub> · 12 H <sub>2</sub> O         |                       | F. = 1 and will stain<br>silver                           | Water                                 |
|   | H., 2.5 Sp. gr., 1.7   |                       |   |                                       |
|   | M. Kainite, p. 420.<br>MgSO <sub>4</sub> · KCl + 3 H <sub>2</sub> O                      | Salty and<br>bitter   |   |                                       |
|   | H., 2.5 to 3   |                       |   |                                       |
|   | Sp. gr., 2 to 2.2  |                       |   |                                       |
|   | M. Borax, p. 456.<br>Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> + 10 H <sub>2</sub> O | Sweetish<br>alkaline  | F. = 1 to 1.5. Swells<br>and gives clear<br>glass         | Puffs up. Gives<br>much water         |
|   | H., 2 to 2.5 Sp. gr., 1.7  |                       |   |                                       |
|   | Tri. Sassolite, p. 456,<br>H <sub>2</sub> BO <sub>3</sub>                                | Acid                  | F. = 2. With in-<br>tumescence to<br>clear glass          | Water and a<br>little ammonia         |
|   | H., 1 Sp. gr., 1.4   |                       |   |                                       |
|   | Tri. Chalcantinite, p.<br>370, CuSO <sub>4</sub> · 5 H <sub>2</sub> O                    | Metallic,<br>nauseous | F. = 3. Reduces<br>with effervescence<br>to copper button | Swells, whitens.<br>Yields water      |
|   | H., 2.5 Sp. gr., 2.2   |                       |   |                                       |
|   |  |                       |   |                                       |

## 25. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.        | Recrystallization in a Drop of Water.                             | Name.         |
|----------------------|----------------------------|---|---------------|
| < Xylol              | Black                      | Isotropic 3, 4, 6-sided polygons                                  | Kalinite      |
|                      | Gray or White              | Doub. refr. 6-sided polygons.                                     | Borax         |
|                      | Aggregate                  | Ex.,    Bright I. C. Ex. Obl.<br>low I. C.                        |               |
|                      | Gray or White to Bright A. | Six-sided plates low I. C., and<br>threads bright I. C.           | Sassolite     |
| = Xylol              | Bright A.                  | Isotropic rectangles, doub. refr.<br>plates, Ex. Obl. and needles | Kainite       |
|                      | Bright A.                  | Isotropic and doub. refr. squares<br>and rectangles               | Carnallite    |
|                      | Bright A.                  | Laths. Ex.,   .   | Thenardite    |
|                      | Black                      | Isotropic squares and aggregates                                  | Sylvite       |
| > Xylol              | Black                      | Isotropic squares and "hoppers"                                   | Halite        |
|                      | Low                        | Rectang. laths and branching.<br>Ex.,   .                         | Aphthitalite  |
|                      | Gray or White              | Spherulitic aggregates  | Trona         |
|                      | Gray or White              | Laths. Ex.,   .   | Mirabilite    |
|                      | Bright A.                  | Blue crystals. Ex. Obl.   | Chalcantinite |
|                      | High Order                 | Laths Ex.,    or polygons Ex.<br>Sym. Aggregates                  | Nitre         |
|                      | High Order                 | Rhombs. Ex. Sym. High I. C.                                       | Soda Nitre    |
|                      |                            |   |               |

## 26. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.  | Taste.             | On Charcoal.                                  | Closed Tube.               |
|--|--------------------|---|----------------------------|
| I. Sal Ammoniac, 430, $\text{NH}_4\text{Cl}$<br>H., 1.5 to 2 Sp. gr., 1.52   | Saline             | White fumes                                   | White subl.                |
| M. Alunogen, p. 415,<br>$\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$<br>H., 1.5 to 2 Sp. gr., 1.6 to 1.8   | Astringent         | Fuses, becomes infus. Deep blue with Co. sol. | Much water a $\text{SO}_2$ |
| M. Melanterite, p. 270,<br>$\text{FeSO}_4 \cdot 7 \text{H}_2\text{O}$<br>H., 2 Sp. gr., 1.9                            | Astringent         | Darkens becomes magnetic                      | Like alunogennd            |
| O. Epsomite, p. 453,<br>$\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$<br>H., 2 to 2.5 Sp. gr., 1.7                        | Bitter             | F. = 1 becomes infus. Pink with Co. sol.      | Much acid water            |
| O. Goslarite, p. 299,<br>$\text{ZnSO}_4 \cdot 7 \text{H}_2\text{O}$<br>H., 2 to 2.5 Sp. gr., 2.0                       | Astringent         | White subl. bright green with Co. sol.        | Water                      |
| M. Copiapite, p. 270,<br>$\text{Fe}_2(\text{OH})_2(\text{SO}_4)_4 \cdot 18 \text{H}_2\text{O}$<br>H., 2.5 Sp. gr., 3.1 | Metallic, nauseous | F. = 4.5 to 5 become magnetic                 | Much acid water            |
| H. Coquimbite, p. 270,<br>$\text{Fe}_2(\text{SO}_4)_3 \cdot 9 \text{H}_2\text{O}$<br>H., 2 to 2.5 Sp. gr., 2.1         | Astringent         | Fuses becomes magnetic                        | Like alunogen              |
| M. Kieserite, p. 453,<br>$\text{MgSO}_4 \cdot \text{H}_2\text{O}$<br>H., 3 to 3.5 Sp. gr., 2.5                         |                    | Fuses   | Much water                 |

## 26. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.     | Recrystallization in a Drop of Water.                         | Name.                    |
|----------------------|-------------------------|---|--------------------------|
| < Xylol              | Gray or White Aggregate | Laths. Ex.,   . Spear points<br>Ex. Sym.<br>Like epsomite     | Epsomite                 |
|                      | Gray or White           | Branching aggregates.<br>Rhombic ends                         | Kieserite<br>Melanterite |
|                      | Gray or White Aggregate | Feathery. Ex.,   .<br>Like epsomite                           | Alunogen<br>Goslarite    |
| > Xylol              | Black                   | Aggregates branching at $60^\circ$ and $90^\circ$ . Isotropic | Sal Ammoniac             |
|                      | Bright B.<br>Bright A.  | No recrystallization<br>Precipitate on heating                | Copiapite<br>Coquimbite  |

## 27. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.  | Fusibility (on Coal). | Closed Tube. | Other Tests.                                       | Usual Color.            |
|--|-----------------------|--------------|--|-------------------------|
| M. Annabergite, p. 294,<br>$\text{Ni}_3(\text{AsO}_4)_2 \cdot 8 \text{H}_2\text{O}$<br>H., 1.5 to 2.5            | 4                     | Water        | See p. 191 for Ni<br>Pale green streak             | Pale green              |
| M. Erythrite, p. 292,<br>$\text{CO}_3(\text{AsO}_4)_2 \cdot 8 \text{H}_2\text{O}$<br>H., 1.5 to 2.5 Sp. gr., 2.9 | 2.5                   | Water        | Borax deep blue.<br>O. F. and R. F.<br>Streak pink | Crimson to pink         |
| O. Olivenite, $\text{Cu}_2(\text{OH})\text{AsO}_4$<br>H., 3 Sp. gr., 4.4   | 2 to 2.5              | Water        | Emerald green<br>Fl.                               | Olive green to blackish |
| H. Mimetite, p. 323,<br>$\text{Pb}_2\text{Cl}(\text{AsO}_4)_2$<br>H., 3.5 Sp. gr., 7                             | 1.5                   | White subl.  | Greenish yellow subl. with Bi<br>Fl.               | Yellow brown            |

| 27. B. (CRUSHED FRAGMENTS.) |   |   | Name.                    |
|-----------------------------|---|---|--------------------------|
| Index of Refraction.        | Interference Color.                     | Other Notable Characters.   |                          |
| < Methylene Iodide          | Aggregate Bright B.                     | Greenish hairs or aggregate laths. Pleochroic pink to red. Ex. about $32^{\circ}$ | Annabergite<br>Erythrite |
| > Methylene Iodide          | Gray or White to Bright A.<br>Bright B. | Irregular. Colorless, greenish<br>Irregular. Green to yellow                      | Mimetite<br>Olivinite    |

## 28. A.

| Crystal System:<br>Name, Composition,<br>Hardness and Specific Gravity.                | Fusibility (on Coal). | Closed Tube.                        | Other Tests.                                       | Usual Color. |
|--|-----------------------|-------------------------------------|--|--------------|
| O. Orpiment, p. 330, $\text{As}_2\text{S}_3$<br>H., 1.5 to 2<br>Sp. gr., 3.4 to 3.6    | 1                     | Boils. Transparent yellow subl.     | Sol. $\text{HNO}_3$ residue S. Streak lemon yellow | Lemon yellow |
| M. Realgar, p. 329, $\text{AsS}$<br>H., 1.5 to 2<br>Sp. gr., 3.4 to 3.6                | 1                     | Boils. Subl. black hot, red cold    | Sol. $\text{HNO}_3$ . Streak orange red            | Orange red   |
| H. Proustite, p. 388, $\text{Ag}_3\text{AsS}_3$<br>H., 2 to 2.5<br>Sp. gr., 5.6 to 5.7 | 1                     | Fuses. Slight red subl. yellow cold | Sol. $\text{HNO}_3$ . Streak scarlet               | Ruby red     |

| 28. B. (CRUSHED FRAGMENTS.) |  |  | Name.                            |
|-----------------------------|--|--|----------------------------------|
| Index of Refraction.        | Interference Color.                                  | Other Notable Characters.  |                                  |
| > Methylene Iodide          | Bright B. or masked<br>Bright B. or masked<br>Masked | Micaceous plates or irregular<br>Irregular. Yellow to orange<br>Irregular. Brownish orange | Orpiment<br>Realgar<br>Proustite |

## 29. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.                                    | Fusibility (on Coal). | Closed Tube.      | Other Tests.                   | Usual Color.       |
|--|-----------------------|-------------------|--------------------------------|--------------------|
| O. Cerussite, p. 323, $\text{PbCO}_3$<br>H., 3 to 3.5<br>Sp. gr., 6.5 to 6.6                         | 1.5                   | Dark yellow subl. | Greenish yellow with Bi flux   | Colorless to white |
| T. Phosgenite, p. 324, $(\text{PbCl})_2\text{CO}_3$<br>H., 3<br>Sp. gr., 6                           | 1.                    | Fusible sublimate | Like cerussite                 | Colorless to white |
| — Bismutite, p. 327, $\text{BiO} \cdot \text{Bi}(\text{OH})_2\text{CO}_3$<br>H., 4.4<br>Sp. gr., 6.9 | 1.5                   | Water             | Chocolate and red with Bi Flux | White to yellow    |

| 29. B. (CRUSHED FRAGMENTS.) |                               |  | Name.                   |
|-----------------------------|-------------------------------|--|-------------------------|
| Index of Refraction.        | Interference Color.           | Other Notable Characters.  |                         |
| > Methylene Iodide          | Bright A. to B.<br>High Order | Rectangular. Ex.,   , El., (+)<br>Irregular or needles with Ex., | Phosgenite<br>Cerussite |
| ?                           | ?                             |  | Bismutite               |

### 30. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.                     | Fusibility (on Coal.) | Closed Tube.                                     | Other Tests.                             | Usual Color.       |
|---|-----------------------|--|--|--------------------|
| M. <b>Kermesite</b> , p. 335,<br>Sb <sub>2</sub> S <sub>2</sub> O                     | 1                     | Blackens, fuses, dark red subl.                  | Vol. white subl. coal. Brown, red streak | Cherry red         |
| H., 1 to 1.5<br>Sp. gr., 4.5 to 4.6   |                       |  |  |                    |
| O. <b>Valentinite</b> , p. 335,<br>Sb <sub>2</sub> O <sub>3</sub>                     | 1.5                   | Fuses, partly sublimates                         | Vol. white subl. coal. Fibrous           | White              |
| H., 2.5 to 3<br>Sp. gr., 5.6  |                       |  |  |                    |
| I. <b>Senarmontite</b> , p. 335,<br>Sb <sub>2</sub> O <sub>3</sub>                    | 1.5                   | As above   | Vol. white subl. Octahedra               | White              |
| H., 2.5 to 3<br>Sp. gr., 5.2  |                       |  |  |                    |
| — <b>Bismite</b> , p. 327, Bi <sub>2</sub> O <sub>3</sub>                             | 1.5(?)                | Water  | Bi† on coal                              | White              |
| H.,<br>Sp. gr., 4.3   |                       |  |  |                    |
| M. <b>Crocoite</b> , p. 346,<br>PbCrO <sub>4</sub>                                    | 1.5                   | KHSO <sub>4</sub> dark violet hot, greenish cold | Pb* on coal. S. Ph. green. Streak orange | Orange red         |
| H., 2.5 to 3<br>Sp. gr., 5.9 to 6.1   |                       |  |  |                    |
| T. <b>Wulfenite</b> , p. 350,<br>PbMoO <sub>4</sub>                                   | 2                     | Darkens, decrepitate                             | Pb* on coal. Mo p. 190                   | Yellow red gray    |
| H., 3<br>Sp. gr., 6.7 to 7  |                       |  |  |                    |
| H. <b>Vanadinite</b> , p. 338,<br>Pb <sub>5</sub> Cl(VO <sub>4</sub> ) <sub>3</sub>   | 1.5                   |  | Pb* on coal. V. p. 196                   | Red brown yellow   |
| H., 3<br>Sp. gr., 6.6 to 7.8  |                       |  |  |                    |
| O. <b>Descloizite</b> , p. 339,<br>(PbOH)VO <sub>4</sub> (Pb,Zn)                      | 3.5                   | Water  | Pb* on coal. V. p. 196                   | Black, brown       |
| H., 3.5<br>Sp. gr., 5.9 to 6.2  |                       |  |  |                    |
| H. <b>Pyromorphite</b> , p. 322,<br>Pb <sub>3</sub> Cl(PO <sub>4</sub> ) <sub>3</sub> | 2                     |  | On coal recrystallizes, Pb*. P. p. 204   | Green, yellow gray |
| H., 3.5 to 4<br>Sp. gr., 5.9 to 7.1   |                       |  |  |                    |
| — <b>Minium</b> , p. 321, Pb <sub>3</sub> O <sub>4</sub>                              | 1.5                   |  | Pb* on coal                              | Red                |
| H., 2 to 3<br>Sp. gr., 4.6  |                       |  |  |                    |

### 30. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.        | Other Notable Characters.                                | Name.                  |
|----------------------|----------------------------|--|------------------------|
| > Methylene Iodide   | Bright B.                  | Needles. Ex.,  | Valentinite            |
|                      | Black                      | Irregular  | Senarmontite           |
|                      | Gray or White to Bright A. | Irregular. Colorless to green                            | Pyromorphite           |
|                      | Bright B.                  | Irregular or Laths. Yellow to orange                     | Vanadinite             |
|                      | Bright B.                  | Irregular. Brown to greenish                             | Descloizite            |
|                      | Bright B.                  | Irregular. Pleochroic, yellow to orange                  | Crocoite               |
|                      | High Order Masked          | Irregular. Yellow Needles. Ex.,   , pleochroic, ruby red | Wulfenite<br>Kermesite |
|                      | ?                          | ?  | Minium                 |
|                      | ?                          | ?  | Bismite                |

\* On coal with Bi Fl, greenish yellow subl.

† On coal with Bi Fl, chocolate and red.

### 31. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity. | Fusibility (on Coal). | Closed Tube and KHSO <sub>4</sub> . |  |           | Usual Color.            |
|---|-----------------------|-------------------------------------|--|-----------|-------------------------|
|   |                       | Hot.                                | Cold.  | Sunlight. |                         |
| H. Iodyrite, p. 392, AgI  | 1                     | Deep red                            | Yellow   | Yellow    | Lemon yellow            |
| H., 1.5 Sp. gr., 5.6 to 5.7                                       |                       |                                     |  |           |                         |
| I. Cerargyrite, p. 391, AgCl                                      | 1                     | Yellow                              | White  | Violet    | Pearl gray to colorless |
| H., 2 to 3 Sp. gr., 5 to 5.5                                      |                       |                                     |  |           |                         |
| I. Bromyrite, p. 392, AgBr  | 1                     | Dark red                            | Yellow   | Green     | Green or yellow         |
| H., 2 to 3 Sp. gr., 5.8 to 6                                      |                       |                                     |  |           |                         |
| I. Embolite, p. 392,  | 1                     | Dark red                            | Yellow   | Green     | Green or yellow         |
| Ag(Cl.Br)   |                       | Closed Tube.                        | On Charcoal.                                     |           |                         |
| H., 2 to 3 Sp. gr., 5.3 to 5.8                                    |                       |                                     |  |           |                         |
| H. Pyrargyrite, p. 389,   | 1                     | Fuses. Subl. black hot, red cold    | White and later pink. In R.F. disappears         |           | Dark red to black       |
| Ag <sub>2</sub> SbS <sub>2</sub>                                  |                       |                                     |  |           |                         |
| H., 2.5 Sp. gr., 5.8  |                       |                                     |  |           |                         |
| M. Linarite, p. 322,  | 1.5                   | Whitens yields water                | With Bi. Fl. yellow subl. and green Fl           |           | Azure blue              |
| [(PbCu)OH] <sub>2</sub> SO <sub>4</sub>                           |                       |                                     |  |           |                         |
| H., 2.5 Sp. gr., 5.3 to 5.4                                       |                       |                                     |  |           |                         |
| O. Anglesite, p. 321, PbSO <sub>4</sub>                           | 2.5                   | Decrepitates                        | With Bi. Fl. yellow subl.                        |           | Colorless or white      |
| H., 3 Sp. gr., 6.1 to 6.4   |                       |                                     |  |           |                         |
| T. Cassiterite, p. 307, SnO <sub>2</sub>                          | 7                     |                                     | With soda white subl. bluish green with Co. sol. |           | Brown to black          |
| H., 6 to 7 Sp. gr., 6.8 to 7.1                                    |                       |                                     |  |           |                         |

### 31. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.                       | Other Notable Characters.                 | Name.       |
|----------------------|---|---|-------------|
| > Methylene Iodide   | Black                                     | Irregular                                 | Cerargyrite |
|                      | Black                                     | Irregular. Greenish                       | Embolite    |
|                      | Black                                     | Irregular                                 | Bromyrite   |
|                      | Black                                     | Irregular. Yellowish                      | Iodyrite    |
|                      | Gray or White to Bright A. Bright B. High | Irregular                                 | Anglesite   |
|                      |   | Laths. Ex.,   . Blue                      | Linarite    |
|                      |   | Irregular. Colorless to pleochroic yellow | Cassiterite |
|                      | Masked                                    | Irregular. Dark red                       | Pyrargyrite |

### 32. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity. | Fusibility. | Closed Tube.              | The Sublimate on Charcoal.                | Usual Color.          |
|---|-------------|---------------------------|---|-----------------------|
| — Hydrozincite, p. 30, ZnCO <sub>3</sub> (OH) <sub>4</sub>        | 7           | Yellow hot yields water   | White non vol. Bright green with Co. sol. | Chalk white           |
| H., 2.5 Sp. gr., 3.6 to 3.8                                       |             |                           |   |                       |
| H. Greenockite, p. 303, CdS                                       | 7           | Car mine hot, yellow cold | Brown. Often iris tarnish                 | Bright yellow         |
| H., 3 to 3.5 Sp. gr., 4.9 to 5                                    |             |                           |   |                       |
| I. Sphalerite, p. 298, ZnS  | 7           |                           | Like hydrozincite                         | Brown to yellow       |
| H., 3.5 to 4 Sp. gr., 3.9 to 4.1                                  |             |                           |   |                       |
| H. Smithsonite, p. 300, ZnCO <sub>3</sub>                         | 7           | Yellow hot, if pure       | Like hydrozincite                         | Brown to nearly white |
| H., 5 Sp. gr., 4.3 to 4.5   |             |                           |   |                       |

| 32. B. (CRUSHED FRAGMENTS.)   |                          |  | Name.                                    |
|-------------------------------|--------------------------|--|--|
| Index of Refraction.          | Interference Color.      | Other Notable Characters.  |  |
| < $\alpha$ Monobrom-Napthalin | Black or Bright A.       | Irregular or Laths with Ex.,   . El. (+)   | Hydrozincite                             |
| > $\alpha$ Monobrom-Napthalin | Black<br>?<br>High Order | Triangles and irregular. Yellow. Cleav. at 60°, 90°<br>Yellow Rhombs with Ex., Sym. or Irregular | Sphalerite<br>Greenockite<br>Smithsonite |

### 33. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.   | Fusibility. | Closed Tube. | The Sublimate on Charcoal.                | Usual Color.            |
|---|-------------|--------------|---|-------------------------|
| O. Calamine, p. 301, (ZnOH) <sub>2</sub> SiO <sub>3</sub>   | 6           | Water        | White non vol. bright green with Co. sol. | White, yellow           |
| H., 5 Sp. gr., 3.4 to 3.5<br>H. Willemite, 301, Zn <sub>2</sub> SiO <sub>4</sub><br>H., 5.5 Sp. gr., 3.9 to 4.2 | 5.5         |              | Like calamine                             | Yellow, brown, greenish |

### 34. A.

|                                     |      |          |                           |                   |
|-------------------------------------|------|----------|---------------------------|-------------------|
| O. Molybdite, 350, MoO <sub>3</sub> | 2(?) |          | White. Deep blue by R. F. | Yellow            |
| H., 1 to 2 Sp. gr., 4.5             |      |          | Like calamine             |                   |
| H. Zincite, p. 299, ZnO             | 7    | Blackens |                           | Deep to brick red |
| H., 4.5 Sp. gr., 5.4 to 5.7         |      |          |                           |                   |

### 35. A.

|   |      |                                     |  |                          |
|---|------|-------------------------------------|--|--------------------------|
| T. Calomel, p. 377, Hg <sub>2</sub> Cl <sub>2</sub> | Vol. | Mirror with soda                    | White volatile                         | White, colorless         |
| H., 1 to 2 Sp. gr., 6.5                             |      |                                     |  |                          |
| O. Sulphur, p. 463, S                               | 1    | Fusible subl. brown hot yellow cold | None, but strong SO <sub>2</sub> fumes | Yellow brown             |
| H., 1.5 to 2.5 Sp. gr., 2.0 to 2.1                  |      |                                     |  |                          |
| H. Cinnabar, p. 376, HgS                            | Vol. | Mirror with soda                    | None                                   | Vermillion, scarlet, red |
| H., 2 to 2.5 Sp. gr., 8.1                           |      |                                     |  |                          |
| I. Gahnite, p. 302, ZnAlO <sub>4</sub>              |      | Unchanged                           | Weak but like calamine                 | Green, brown, black      |
| H., 7.5 to 8 Sp. gr., 4 to 4                        | 7    |                                     |  |                          |

### 33. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.          | Interference Color. | Other Notable Characters.     | Name.     |
|-------------------------------|---------------------|-------------------------------|-----------|
| < $\alpha$ Monobrom-Napthalin | Bright B.           | Laths. Ex.,   . El. (+)       | Calamine  |
| > $\alpha$ Monobrom-Napthalin | Bright A. to B.     | Irregular. Colorless to brown | Willemite |

### 34. B.

|                    |             |  |                      |
|--------------------|-------------|--|----------------------|
| > Methylene Iodide | Masked<br>? | Laths or irregular. Yellow to orange<br>Minute needles, Ex., | Zincite<br>Molybdite |
|--------------------|-------------|--|----------------------|

### 35. B.

|                    |   |   |   |
|--------------------|---|---|---|
| > Methylene Iodide | Masked<br>High Order<br>Black<br>High Order | Irregular. Brilliant red Rhombs and rectangles<br>Irregular | Cinnabar<br>Calomel<br>Gahnite<br>Sulphur |
|--------------------|---|---|---|

### 36. A.

| Crystal System:<br>Name, Composition,<br>Hardness and Specific Gravity.     | Fusibil-<br>ity. | Closed Tube.        | Streak.                 | Usual Color.                                       |
|---|------------------|---------------------|-------------------------|--|
| H. Siderite, p. 275, $\text{FeCO}_3$<br>H., 3.5 to 4<br>Sp. gr., 3.8 to 3.9 | 5                | Black mag-<br>netic | Nearly white if<br>pure | Light to dark<br>brown. Cleav-<br>able or granular |

### 37. A.

|   |          |                              |                 |  |
|---|----------|------------------------------|-----------------|--|
| M. Vivianite, p. 472,<br>$\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$<br>H., 1.5 to 2<br>Sp. gr., 2.6 to 2.7      | 2 to 2.5 | Water.<br>(Turns<br>brown)   | Blue            | Bluish green<br>earthy to<br>blackish blue<br>crystals |
| —, Garnierite, p. 294,<br>$\text{H}_2(\text{Ni,Mg})\text{SiO}_3 \cdot \text{H}_2\text{O}$<br>H., 2 to 3 Sp. gr., 2.3 to 2.8 | 7        | Water de-<br>crepitates      | Pale green      | Deep green to<br>pale green                            |
| —, Limonite, p. 274,<br>$\text{Fe}_2\text{O}_3 \cdot \text{Fe}_2(\text{OH})_4$<br>H., 5 to 5.5 Sp. gr., 3.6 to 4            | 5 to 5.5 | Much water.<br>Reddens       | Yellowish brown | Yellowish brown<br>to nearly black.<br>Not crystals    |
| O. Goethite, p. 273,<br>$\text{FeO}(\text{OH})$<br>H., 5 to 5.5 Sp. gr., 4 to 4.4   | 5 to 5.5 | Water.<br>Reddens            | Yellowish brown | Yellowish brown<br>to nearly black.<br>Often crystals  |
| —, Turgite, p. 274,<br>$\text{Fe}_2\text{O}_3(\text{OH})_3$<br>H., 5.5 to 6<br>Sp. gr., 4.3 to 4.7                          | 5 to 5.5 | Flies to<br>pieces.<br>Water | Brownish red    | Red to black<br>crusts                                 |
| H. Hematite, p. 271, $\text{Fe}_2\text{O}_3$<br>H., 5.5 to 6.5<br>Sp. gr., 4.9 to 5.3                                       | 7        |                              | Brownish red    | Dull dark red  |

### 36. B. (CRUSHED FRAGMENTS.)

| Index of<br>Refraction. | Interference<br>Color. | Other Notable Characters.  | Name.    |
|-------------------------|------------------------|--|----------|
| > Methylene<br>Iodide   | High Order             | Rhombs. Ex. Sym.<br>Index    short diag. closely<br>that of methylene iodide | Siderite |

### 37. B.

|                       |  |  |   |
|-----------------------|--|--|---|
| < Methylene<br>Iodide | Gray or White.<br>Aggregate<br>Bright B.       | Irregular. Greenish<br><br>Laths. Ex.,   . El., (+) or<br>Ex. 30° El., (-). Pleochroic<br>blues or colorless                           | Garnierite<br><br>Vivianite                         |
| > Methylene<br>Iodide | Bright B.<br><br>High Order<br><br>?<br>Masked | Yellow fibres, Ex., Obl., and<br>irregular, opaque<br>Laths Ex.,   . Pleochroic yel-<br>low<br>Irregular. Opaque<br>Dark red or opaque | Limonite<br><br>Goethite<br><br>Turgite<br>Hematite |

### 38. A.

| Crystal System :<br>Name, Composition,<br>Hardness and Specific Gravity.                                      | Fusibil-<br>ity. | Flame<br>Coloration. | Other Tests.                                       | Usual Appearance.                          |
|---|------------------|----------------------|--|--|
| M. Gaylussite, p. 427,<br>$\text{CaNa}_2(\text{CO}_3)_2 \cdot 5\text{H}_2\text{O}$<br>H., 2 to 3 Sp. gr., 1.9 | 1.5              | Yellow               | Closed tube<br>water                               | White crystals                             |
| O. Witherite, p. 433,<br>$\text{BaCO}_3$<br>H., 3 to 4 Sp. gr., 4.3   | 2                | Yellowish<br>green   | Solution gives<br>ppt with $\text{H}_2\text{SO}_4$ | White columnar<br>and pseudo-<br>hexagonal |
| H. Cancrinite, p. 570,<br>$\text{R}(\text{Na}_2\text{CO}_3)(\text{SiO}_4)$<br>H., 5 to 6 Sp. gr., 2.4         | 2                | Yellow               | Jelly on heating<br>solution                       | Yellow or white<br>massive                 |

### 39. A.

|   |     |                                  |  |  |
|---|-----|----------------------------------|--|--|
| O. Thomsonite, p. 534,<br>$(\text{Na}_2\text{Ca})\text{Al}_2\text{Si}_2\text{O}_8 + 5\text{H}_2\text{O}$<br>H., 5 to 5.5 Sp. gr., 2.4       | 2   |                                  | Intumesces.<br>Much water                                      | White radiated<br>or green spher-<br>ical  |
| M. Pectolite, p. 535,<br>$\text{HNa}_2\text{Ca}(\text{SiO}_3)_2$<br>H., 5 Sp. gr., 2.7  | 2   | Yellow                           | Water in closed<br>tube  | White radiating<br>fibres  |
| M. Wollastonite, p. 507,<br>$\text{CaSiO}_3$<br>H., 4.5 to 5 Sp. gr., 2.8   | 4   | Red                              | Often effervesce<br>from calcite                               | White semi-<br>fibrous or gray<br>crystals   |
| I. Lazurite, p. 576,<br>$\text{Na}_4(\text{Na}_2\text{Al})\text{Al}_2(\text{SiO}_4)_2$<br>H., 5 to 5.5 Sp. gr., 2.4                         | 3.5 | Yellow                           | Blue in fine<br>powder. Odor<br>$\text{H}_2\text{S}$ with acid | Deep blue, usu-<br>ally spangled<br>with pyrite  |
| H. Chabazite, p. 532,<br>$(\text{CaNa}_2)\text{Al}(\text{SiO}_4)_6\text{H}_2\text{O}$<br>H., 4.5 Sp. gr., 2.0 to 2.1                        | 3   |                                  | Intumesces   | Nearly cubic;<br>Striated.<br>White and pink   |
| T. Apophyllite, p. 534,<br>$\text{H}_{14}\text{K}_2\text{Ca}_8(\text{SiO}_3)_{10}\text{H}_2\text{O}$<br>H., 4.5 to 5<br>Sp. gr., 2.3 to 2.4 | 2   | Pale violet<br>(Color<br>Screen) | One easy cleav-<br>age. Exfoliates<br>during fusion            | Colorless cubic<br>or pointed<br>crystals with<br>opalescence in<br>direction $\epsilon$ |

### 38. B (CRUSHED FRAGMENTS.)

| Index of<br>Refraction. | Interference<br>Color. | Other Notable Characters.                  | Name.      |
|-------------------------|------------------------|--|------------|
| < Bromoform             | Bright A.              | Plates or Laths. Ex.,                      | Cancrinite |
| > Bromoform             | High Order             | Plates or Laths with Ex.,   .<br>El., (—). | Witherite  |

### 39. B.

|             |  |   |                           |
|-------------|--|---|---------------------------|
| < Bromoform | Black<br>Gray or White                         | Blue included particles<br>Rectangular. Ex.,    or iso-<br>tropic with uniaxial I. F. | Lazurite<br>Apophyllite   |
|             | Gray or White<br>Gray or White<br>to Bright A. | Rhombs. Ex. Sym.<br>Laths. Ex.,   | Chabazite<br>Thomsonite   |
| > Bromoform | Gray or White<br>Bright A.                     | Laths or Needles. Ex.   .<br>El., (+)<br>Needles. Ex.,   . El., (+)                   | Wollastonite<br>Pectolite |



## 40. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.   | Fusibility. | Flame Coloration. | Other Tests.   | Usual Appearance.   |
|---|-------------|-------------------|--|---|
| <b>M. Gypsum</b> , p. 443.<br>$\text{CaSO}_4 + 2\text{H}_2\text{O}$<br>H., 1.5 to 2 Sp. gr., 2.3  | 3 to 3.5    | Yellowish red     | Cleaves to a rhombic plate of $66^\circ$ . Solution recrystallizes | Colorless "selenite." White or tinted scaly or fibrous masses |
| <b>M. Cryolite</b> , p. 412.<br>$\text{AlNa}_3\text{F}_6$<br>H., 2.5 Sp. gr., 2.9 to 3  | 1.5         | Yellow            | Blue if ignited with Co. sol.                                      | Translucent resembling watery snow                            |
| <b>O. Anhydrite</b> , p. 442.<br>$\text{CaSO}_4$<br>H., 3 to 3.5 Sp. gr., 2.9 to 3  | 3 to 3.5    | Yellowish red     | Cleaves three directions at $90^\circ$                             | Blue and white. Cleavable and fine-grained                    |
| <b>M. Heulandite</b> , p. 534.<br>$\text{H}_4\text{CaAl}_2(\text{SiO}_3)_6 + 3\text{H}_2\text{O}$<br>H., 3.5 to 4 Sp. gr., 2.2              | 3           |                   | Swells with heat. Lozenge shaped pearly face                       | White or red crystals   |
| <b>M. Stilbite</b> , p. 533.<br>$\text{H}_4\text{R}_2\text{Al}_2(\text{SiO}_3)_6 + 4\text{H}_2\text{O}$<br>H., 3.5 to 4 Sp. gr., 2.1 to 2.2 | 3           |                   | Swells greatly during fusion. Symmetrical pearly face              | Sheaf-like groups or many small brown or white crystals       |
| <b>I. Fluorite</b> , p. 441, $\text{CaF}_2$<br>H., 4 Sp. gr., 3 to 3.3  | 3           | Red to orange     | Phosphorescent. Cleavages at $70^\circ 31'$                        | Glassy cubes of purple yellow and green                       |
| <b>M. Harmotome</b> , p. 534.<br>$(\text{BaK}_2)\text{Al}_2\text{Si}_2\text{O}_{14} \cdot 5\text{H}_2\text{O}$<br>H., 4.5 Sp. gr., 2.5      | 3           |                   | Whitens before fusing  | White or colorless crossed twins                              |
| <b>T. Wernerite</b> , group p. 515.<br>(Silicates of NaCaAl)<br>H., 5 to 6 Sp. gr., 2.7   | 3           | Yellow            | Bubbles in fused material. Cleavages at $90^\circ$                 | Gray and greenish octagonal or square prisms                  |
| <b>O. Prehnite</b> , p. 535.<br>$\text{H}_2\text{Ca}_2\text{Al}_2(\text{SiO}_3)_4$<br>H., 6 to 6.5 Sp. gr., 2.8 to 2.9                      | 2.5         |                   | Intumesces. Bubbles in fused material                              | Green rounded crusts or sheaf-like groups                     |
| <b>I. Boracite</b> , p. 458.<br>$\text{Mg}_7\text{Cl}_2\text{B}_{10}\text{O}_{20}$<br>H., 7 Sp. gr., 2.9 to 3                               | 3           | Yellowish green   | Violet if ignited with Co. sol.                                    | Minute glassy crystals  |

## 40. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.   | Interference Color.        | Other Notable Characters.                                      | Name.                               |
|------------------------|----------------------------|--|-------------------------------------|
| < Xylol                | Black                      | Polygons 3, 4, 5 or 6-sided, angles $60^\circ$ and $120^\circ$ | <b>Fluorite</b>                     |
|                        | Gray or White              | Roughly rectangular<br>Ex. Obl. large angle                    | <b>Cryolite</b>                     |
| > Xylol<br>< Bromoform | Gray or White              | Laths. Ex.,   . El., (-) or Ex., $25^\circ$ to $30^\circ$      | <b>Heulandite</b>                   |
|                        | Gray or White to Bright A. | Rhombic Laths and Fibers.<br>Ex. Obl.                          | <b>Gypsum</b>                       |
|                        | Gray or White to Bright A. | Laths. Ex.,   . El., (-)                                       | <b>Stilbite</b>                     |
|                        | Bright B.                  | Rectangles. Ex.,   . Diagonal striations                       | <b>Anhydrite</b>                    |
| > Bromoform            | Bright B. or High Order    | Laths. Ex.,   . El., (-). Inclusions                           | <b>Wernerite</b>                    |
|                        | Bright A.                  | Laths. Ex.,   . El., (-) and irregular                         | <b>Prehnite</b>                     |
|                        | Bright A.<br>Bright B.     | Irregular<br>See above   | <b>Boracite</b><br><b>Anhydrite</b> |

## 41. A.

| Crystal System:<br>Name, Composition,<br>Hardness and Specific Gravity.   | Fusibil-<br>ity. | Flame<br>Coloration.                            | Other Tests.   | Usual Appearance.                             |
|---|------------------|---|--|---|
| M. Lepidolite, p. 429.<br>(KLi) <sub>2</sub> Al(SiO <sub>3</sub> ) <sub>3</sub><br>H., 2.5 Sp. gr., 2.8 to 3.2                  | 2                | Crimson   | Acid water in closed tube.<br>Easy cleavage                            | Lilac or pink scaly masses or gray plates     |
| O. Barite, p. 432, BaSO <sub>4</sub><br>H., 2.5 to 3.5<br>Sp. gr., 4.3 to 4.6   | 4                | Yellowish green                                 | Cleaves to rhombic plates of 78°. Heavy                                | White and tinted crystals and masses          |
| O. Celestite, p. 435, SrSO <sub>4</sub><br>H., 3 to 3.5 Sp. gr., 4  | 3.5 to 4         | Crimson   | Cleaves to rhombic plates of 76°. Heavy<br>Cleavage and prism 124° 30' | Pale blue white crystals and fibrous          |
| M. Amphibole, (tremolite),<br>p. 508, CaMg <sub>3</sub> (SiO <sub>3</sub> ) <sub>4</sub><br>H., 5 to 6 Sp. gr., 2.9 to 3.4      | 4                |   |  | White fibrous radiating or prisms             |
| M. Pyroxene, (diopside),<br>p. 506, CaMg(SiO <sub>3</sub> ) <sub>2</sub><br>H., 5 to 6 Sp. gr., 3.2 to 3.6                      | 4                |   | Cleavage and prism 87° 51'   | White or green inclined 8-sided prisms        |
| O. Zoisite, p. 528,<br>Ca <sub>2</sub> (AlOH)Al <sub>2</sub> (SiO <sub>4</sub> ) <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 3.3      | 3 to 3.5         |   | Swells and fuses to bubbly glass                                       | Gray brown columnar. One easy cleavage        |
| M. Petalite, p. 430,<br>LiAl(Si <sub>2</sub> O <sub>6</sub> ) <sub>2</sub><br>H., 6 to 6.5 Sp. gr., 2.4                         | 4                | Crimson   | Phosphorescent on heating  | Colorless or white cleavable                  |
| Tri. Plagioclase, p. 494.<br>See 44.A.  | 4 to 4.5         | Yellow  | Cleavage 87° approx.   | White, gray, red. Striated                    |
| Tri. Amblygonite, p. 428,<br>Li(AlF)PO <sub>4</sub><br>H., 6 Sp. gr., 3 to 3.1  | 2                | Crimson to yellowish red                        | Momentary blue-green Fl. with H <sub>2</sub> SO <sub>4</sub>           | White masses with one easy cleavage           |
| H. Tourmaline, p. 524,<br>R <sub>3</sub> B <sub>3</sub> (SiO <sub>3</sub> ) <sub>4</sub><br>H., 6 to 6.5<br>Sp. gr., 2.8 to 2.9 | 3.5              | Green with KHSO <sub>4</sub> + CaF <sub>2</sub> | Electric by heat or friction   | Brown prisms often trigonal and hemimorphic   |
| M. Spodumene, p. 429,<br>LiAl(SiO <sub>3</sub> ) <sub>2</sub><br>H., 6.5 to 7<br>Sp. gr., 3.1 to 3.2                            | 3.5              | Crimson   | Sprouts during fusion. Cleavage at 87°                                 | White, green and pink crystals often lamellar |

## 41. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.                   | Interference Color.                           | Other Notable Characters.  | Name.  |
|--|---|--|--|
| < Bromoform                            | Gray or White to Bright A.                    | Laths and Plates. Twinning   | Plagioclase  |
|  | Bright A. to B.                               | See p. 491 for varieties<br>Plates   | Petalite<br>Amblygonite                            |
| > Bromoform<br>< α-Monobrom-Naphthalin | Gray or White to Bright A.                    | Rectangular, Ex.,   ; or rhombic, Ex. Sym.; or irregular   | Barite   |
|  |   | Like barite<br>Plates and Rhombs. Biax.<br>Laths or fibres. Ex. Obl.<br>El. (+). See p. 502<br>Irregular | Celestite<br>Lepidolite<br>Amphibole<br>Tourmaline |
| > α-Monobrom-Naphthalin                | Gray or White                                 | Plates   | Zoisite  |
|  | Gray or White to Bright A.<br>Bright A. to B. | Laths. Ex., 20°-25° El., (+)<br>Laths and Rhombs. Ex.<br>Obl. see p. 502                                 | Spodumene<br>Pyroxene                              |

## 42. A.

| Crystal System; Name, Composition, Hardness and Specific Gravity.                      | Fusibility. | Flame Coloration. | Other Tests.                 | Usual Appearance.  |
|--|-------------|-------------------|------------------------------|--|
| H. <b>Nephelite</b> , p. 499.<br>$\text{Na}_2\text{Al}_2\text{Si}_6\text{O}_{14}$      | 4           | Yellow            | Blue with Co. sol.           | Gray or reddish, greasy massive. Also small white prisms |
| H., 5 to 6<br>Sp. gr., 2.2 to 2.6  |             |                   |                              |  |
| O. <b>Natrolite</b> , p. 532.<br>$\text{Na}_2\text{Al}_2\text{Si}_6\text{O}_{10}$      | 2.5         | Yellow            | Quiet fusion                 | White needles nearly square with flat pyramidal ends     |
| H., 5 to 5.5<br>Sp. gr., 2.2   |             |                   |                              |  |
| I. <b>Analcite</b> , p. 531.<br>$\text{NaAl}(\text{SiO}_3)_2 \cdot \text{H}_2\text{O}$ | 3           | Yellow            | Becomes opaque before fusion | White or colorless trapezohedra                          |
| H., 5 to 5.5<br>Sp. gr., 2.2 to 2.3  |             |                   |                              |  |
| M. <b>Datolite</b> , p. 536.<br>$\text{Ca}(\text{BOH})\text{SiO}_4$                    | 2 to 2.5    | Green             | Intumesces                   | Bright colorless complex crystals. Porcelain masses      |
| H., 5 to 5.5<br>Sp. gr., 2.9 to 3  |             |                   |                              |  |
| I. <b>Sodalite</b> , p. 500<br>$\text{Na}_4\text{Al}_3\text{Cl}_3\text{Si}_3$          | 3.5 to 4    | Yellow            | Closed tube whitens          | Gray, blue, etc. massive and crystals                    |
| H., 5.5 to 6<br>Sp. gr., 2.2   |             |                   |                              |  |

## 43. A.

|   |          |                |  |  |
|---|----------|----------------|--|--|
| — <b>Ulexite</b> , p. 457.<br>$\text{CaNaB}_3\text{O}_6 \cdot 8\text{H}_2\text{O}$                      | 1.5      | Reddish yellow |  | White fibres in "Cotton balls"                         |
| H., 1<br>Sp. gr., 1.65  |          |                |  |  |
| M. <b>Colemanite</b> , p. 458.<br>$\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$        | 1.5      | Green          | Solutions deposit crystals of sassolite  | Colorless complex crystals. White, chalky or porcelain |
| H., 4 to 4.5<br>Sp. gr., 2.2 to 2.3   |          |                |  |  |
| Tri. <b>Plagioclase</b> , p. 494.<br>$x\text{NaAlSi}_3\text{O}_8 + m\text{CaAl}_2\text{Si}_2\text{O}_8$ | 4 to 4.5 | Yellow         | Two easy cleavages ( $86^\circ$ , $87^\circ$ , etc.). Varieties by scheme p. 491 | White, gray, reddish, cleavable, striated              |
| H., 5 to 6.5<br>Sp. gr., 2.5 to 2.8   |          |                |  |  |

## 42. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.        | Other Notable Characters.                | Name.            |
|----------------------|----------------------------|--|------------------|
| Equal                | Black or Gray or White     | Irregular glassy                         | <b>Analcite</b>  |
| Xylol                | Black                      |  | <b>Sodalite</b>  |
|                      | Gray or White to Bright A. | Needles and Laths. Ex.,   . El. (+)      | <b>Natrolite</b> |
| > Xylol              | Gray or White              | Irregular or Laths with Ex.,   . El. (-) | <b>Nephelite</b> |
| < Bromoform          |                            |  |                  |
| > Bromoform          | Bright B.                  | Irregular                                | <b>Datolite</b>  |

## 43. B.

|                      |                            |                                     |                    |
|----------------------|----------------------------|-------------------------------------|--------------------|
| < Bromoform          | Gray or White              | Fine needles. Ex.,   . El. (-)      | <b>Ulexite</b>     |
|                      | Gray or White or Bright A. | Plates and Laths. Ex. Obl. see p. — | <b>Plagioclase</b> |
| Equal or > Bromoform | Bright A.                  | Plates                              | <b>Colemanite</b>  |

**44.** Certain varieties of **Plagioclase**, **Amphibole**, **Pyroxene** and **Spodumene** may work out here. In this case use 41. A. and B.

#### 45. A.

| Crystal System :<br>Name, Composition,<br>Hardness and Specific Gravity.                                 | Fusi-<br>bility. | Flame<br>Coloration.    | Other Tests.                        | Usual Appearance.                                       |
|--|------------------|-------------------------|-------------------------------------|---|
| <b>M. Malachite</b> , p. 371,<br>$\text{Cu}_2(\text{OH})_2\text{CO}_3$<br>H., 3.5 to 4 Sp. gr., 3.9 to 4 | 3                | Green, blue<br>with HCl | Closed tube,<br>black much<br>water | Bright green<br>fibrous in-<br>crusting or dull         |
| <b>M. Azurite</b> , p. 371,<br>$\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$<br>H., 3.5 to 4 Sp. gr., 3.8    | 3                | Like mala-<br>chite     | Like malachite.<br>Streak blue      | Dark-blue glassy<br>crystals, velvety<br>or dull crusts |

#### 46. A.

|   |     |  |                             |  |
|---|-----|--|-----------------------------|--|
| <b>T. Mellilite</b> , p. 499,<br>Complex Silicate<br>H., 5 Sp. gr., 2.9 to 3.1          | 3   |  | Intumesces                  | White or yellow-<br>ish small<br>square prisms |
| <b>M. Allanite</b> , p. 529,<br>"Cerium Epidote"<br>H., 5.5 to 6 Sp. gr., 3.5 to 4      | 2.5 |  | Swells, becomes<br>magnetic | Black "nail" or<br>plate crystals              |
| <b>O. Tephroite</b> , p. 285,<br>$\text{Mn}_2\text{SiO}_4$<br>H., 5.5 to 6 Sp. gr., 4.1 | 3.5 |  | Amethyst borax<br>bead      | Ash gray to red-<br>dish masses                |

#### 45. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.  | Interference Color | Other Notable Characters.                                    | Name.                              |
|-----------------------|--------------------|--|------------------------------------|
| > Methylene<br>Iodide | Masked<br>Masked   | Irregular. Blue<br>Laths. Ex. Obl. Arrowhead<br>twins. Green | <b>Azurite</b><br><b>Malachite</b> |

#### 46. B.

|                                     |                            |  |                       |
|-------------------------------------|----------------------------|--|-----------------------|
| < $\alpha$ -Monobrom-<br>Naphthalin | Gray or White<br>Bright B. | Plates<br>Irregular. Brown, pleochroic | Mellilite<br>Allanite |
| > Methylene<br>Iodide               | High Order                 | Plates. Pleochroic                     | Tephroite             |

#### 47. A.

| Crystal System :<br>Name, Composition,<br>Hardness and Specific Gravity.  | Fusi-<br>bility. | Flame<br>Coloration.    | Other Tests.   | Usual<br>Appearance.                               |
|---|------------------|-------------------------|--|--|
| <b>O. Autunite</b> , p. 345,<br>$\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$<br>H., 2 to 2.5 Sp. gr., 3 to 3.2       | 3                | Yellowish<br>red        | Borax colorless<br>O. F., green<br>R. F. See p.<br>195 | Yellow square<br>plates scales<br>and aggregates   |
| <b>T Torbernite</b> , p. 345,<br>$\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$<br>H., 2 to 2.5<br>Sp. gr., 3.4 to 3.6 | 3                | Azure blue<br>with HCl  | Borax green O<br>F. red R. F.                          | Pearly green<br>plates                             |
| <b>O. Atacamite</b> , p. 370,<br>$\text{Cu}_2(\text{OH})_2\text{Cl}$<br>H., 3 to 3.5<br>Sp. gr., 3.7 to 3.8                                 | 3 to 4           | Azure blue              | White and red<br>sublimates                            | Emerald-green,<br>aggregates and<br>prisms         |
| <b>O. Brochantite</b> , p. 370,<br>$\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$<br>H., 3.5 to 4 Sp. gr., 3.9                               | 3.5              | Green, blue<br>with HCl | Fused with soda<br>stains silver                       | Emerald-green<br>needles and<br>crusts             |
| <b>I. Cuprite</b> , p. 368, $\text{Cu}_2\text{O}$<br>H., 3.5 to 4<br>Sp. gr., 5.8 to 6.1  | 3                | Azure-blue<br>with HCl  | Streak brownish<br>red                                 | Dark-red<br>masses and<br>crystals or<br>hair-like |

| 47. B. (CRUSHED FRAGMENTS.)     |                     |   | Name.                  |
|---------------------------------|---------------------|---|------------------------|
| Index of Refraction.            | Interference Color. | Other Notable Characters.                                 |                        |
| < Bromoform                     | Gray or White       | Plates. Pale yellow                                       | Autunite               |
| > Bromoform                     | Black               | Rectangles. Uniax. Green                                  | Torbernite             |
| < $\alpha$ -Monobrom-Naphthalin | Bright A.           | Laths. Ex.,   , El., (-) or Irregular                     | Prehnite               |
| > Methylene Iodide              | Black Bright A.     | Irregular or Needles. Red Laths. Ex.,   , El., (+). Green | Cuprite<br>Brochantite |
|                                 | Masked              | Plates or Laths. Ex.,   , Green                           | Atacamite              |

#### 48. A.

| Crystal System:<br>Name, Composition, Hardness<br>and Specific Gravity,  | Fusibility. | Flame<br>Colora-<br>tion. | Other Tests.  | Usual Appearance.  |
|--|-------------|---------------------------|---|--|
| M. Roscoelite, p. 340,<br>"Vanadium Mica"  | 3           |                           | S. Ph. O. F. yellow<br>R. F. green                                | Dark green<br>scales   |
| H., 2 ? Sp. gr., 2.9<br>— Crocidolite, p. 509, NaFeSi  | 3.5         | Yellow                    | After fusion is<br>magnetic                                       | Blue fibres  |
| H., 4 Sp. gr., 3.3<br>M. Titanite, p. 525,<br>CaSiTiO <sub>6</sub>   | 4           |                           | S. Ph. O. F. then<br>R. F. violet<br>Cleavages 113°               | Brown or green<br>"envelope"<br>and wedge<br>shaped crystals                 |
| H., 5 to 5.5 Sp. gr., 3.4 to 3.5   |             |                           |   | Green to black<br>inclined prisms<br>87° 5'                                  |
| M. Pyroxene, p. 505,<br>RSiO <sub>3</sub> . Many varieties   | 4           |                           | Cleavage and<br>prism angles<br>87° 5'                            | 8-sided.   |
| H., 5 to 6 Sp. gr., 3.2 to 3.6   |             |                           |   | Green to black<br>fibrous or prismatic with<br>rhombic or six-sided section. |
| M. Amphibole, p. 507,<br>RSiO <sub>3</sub> . Many varieties  | 4           |                           | Cleavage and<br>prism angles<br>124° 30'                          | Black foliated<br>sometimes<br>pearly  |
| H., 5 to 6 Sp. gr., 3.4 to 3.5   |             |                           | After fusion is<br>magnetic                                       | Red or brown<br>fine-grained or<br>cleavable.                                |
| O. Hypersthene, p. 505,<br>(Mg.Fe)SiO <sub>3</sub>   | 5           |                           | Borax, O. F.<br>amethystine                                       | Pistache or<br>blackish green<br>grains or<br>needles                        |
| Tri. Rhodonite, p. 284,<br>MnSiO <sub>3</sub>  | 3 to 3.5    |                           | After fusion will<br>gelatinize<br>Water in closed<br>tube        | Brown, or green<br>square prisms<br>or columnar or<br>compact                |
| H., 6 to 6.5 Sp. gr., 3.4 to 3.7<br>M. Epidote, p. 528,<br>Ca <sub>2</sub> (Al.Fe) <sub>2</sub> (AlOH)(SiO <sub>4</sub> ) <sub>2</sub> | 3 to 4      |                           | After fusion will<br>gelatinize.<br>Water in closed<br>tube       | Brown or violet.<br>"Axe" shaped   |
| H., 6 to 7 Sp. gr., 3.2 t. 3.5   |             |                           |   |  |
| T. Vesuvianite, p. 511,<br>Ca <sub>2</sub> Al <sub>2</sub> (OH.F)(SiO <sub>4</sub> ) <sub>2</sub>                                      | 3           |                           | Intumesces  | Brown or red 12,<br>24 and 36 faced<br>crystals                              |
| H., 6.5 Sp. gr., 3.3 to 3.4  |             |                           | After fusion will<br>gelatinize. Often<br>nearly spherical        |  |
| Tri. Axinite, p. 570,<br>H <sub>2</sub> R <sub>4</sub> (BO)Al <sub>2</sub> (SiO <sub>4</sub> ) <sub>2</sub>                            | 2 to 3      | Green<br>with<br>Bo. Fl.  |   |  |
| H., 6.5 to 7 Sp. gr., 3.3  |             |                           |   |  |
| I. Garnet, p. 509,<br>R <sub>2</sub> R <sub>3</sub> (SiO <sub>4</sub> ) <sub>3</sub>   | 3 to 4      |                           | After fusion will<br>gelatinize. Often<br>roughly tri-<br>angular |  |
| H., 6.5 to 7.5<br>Sp. gr., 3.1 to 4.3  |             |                           |   |  |
| H. Tourmaline, p. 524,<br>R <sub>12</sub> B <sub>2</sub> (SiO <sub>4</sub> ) <sub>4</sub>  | 3 to 5      | Green<br>with<br>Bo. Fl.  |   |  |
| H., 7 to 7.5 Sp. gr., 3 to 3.2   |             |                           |   |  |

(CRUSHED FRAGMENTS.)

**49. A.**

**50. A.**

## 51. A.

| Crystal System:<br>Name, Composition, Hardness<br>and Specific Gravity.  | Fusibility | Flame<br>Colora-<br>tion. | Other Tests.  | Usual Appearance.  |
|--|------------|---------------------------|---|--|
| M. Biotite, p. 540,<br>(H. K) <sub>2</sub> (Mg. Fe) <sub>2</sub> Al <sub>2</sub> (SiO <sub>4</sub> ) <sub>2</sub><br>H., 2.5 to 3 Sp. gr., 2.7 | 5          |                           | Cleaves to thin<br>elastic plates                         | Black "mica"<br>rarely in large<br>sheets                                |
| — Serpentine, p. 544,<br>H <sub>2</sub> Mg <sub>3</sub> Si <sub>2</sub> O <sub>6</sub><br>H., 3 to 4 Sp. gr., 2.5 to 2.6                       | 5 to 5.5   |                           | Pink if ignited<br>with Co. Sol.                          | Mottled yellow,<br>green, feeble<br>lustre or silky                      |
| H. Apatite, p. 470,<br>Ca <sub>5</sub> (Cl. F) (PO <sub>4</sub> ) <sub>3</sub><br>H., 4.5 to 5 Sp. gr., 3.2                                    | 5          | Yellow-<br>ish red        | Easy solution<br>P. test p. 191                           | Green, red and<br>white prisms.<br>Resinous lustre.<br>White compact     |
| T. Scheelite, p. 353, CaWO <sub>4</sub><br>H., 4.5 to 5 Sp. gr., 5.9 to 6.1  | 5          | Pale red                  | S. Ph. O. F.<br>colorless to<br>white. R. F.<br>deep blue | Heavy yellowish<br>masses, resin-<br>ous lustre.<br>Square pyra-<br>mids |
| O. Iolite, p. 529,<br>H <sub>2</sub> (Mg, Fe) <sub>4</sub> Al <sub>2</sub> Si <sub>10</sub> O <sub>37</sub><br>H., 7 to 7.5 Sp. gr., 2.6       | 5 to 5.5   |                           | A little water in<br>closed tube                          | Like blue or<br>purple quartz.<br>Often altered                          |

## 49. B. (CRUSHED FRAGMENTS.)

| Index of<br>Refraction.     | Interference<br>Color. | Other Notable Characters. | Name.         |
|-----------------------------|------------------------|---------------------------|---------------|
| < α-Monobrom-<br>Naphthalin | High order             | Laths. Ex.,   . El. (—)   | Strontianite  |
| > α-Monobrom-<br>Naphthalin | High order             | Laths. Ex. Obl.           | Barytocalcite |

## 50. B. (CRUSHED FRAGMENTS.)

|             |   |   |                        |
|-------------|---|---|------------------------|
| < Bromoform | Gray or White<br>Aggregate<br>Gray or White<br>to Bright A. | Fibres. Ex.,   . El. (+)<br>or irregular<br>Laths. Ex., 35°—40° | Sepiolite<br>Anorthite |
| > Bromoform | Gray or White   | Laths or Needles. Ex.,   .<br>El. (+)                           | Wollastonite           |

## 51. B. (CRUSHED FRAGMENTS.)

|                                      |   |  |   |
|--------------------------------------|---|--|---|
| < Bromoform                          | Gray or White.<br>Aggregate<br><br>Gray or White<br>Gray or White<br>to Bright A. | Fibres. Ex.,   . El. (+).<br>or irregular<br><br>Pleochroic if colored | Serpentine<br><br>Chrysotile<br>Antigorite<br>Biotite<br>Iolite |
| > Bromoform<br>< Methylene<br>Iodide | Gray or White   | Irregular. Ex.,    cleavages   | Apatite   |
| > Methylene<br>Iodide                | Bright A.   | Irregular  | Scheelite   |

## 52. A

| Crystal System: Name, Composition, Hardness and Specific Gravity.                           | Fusibility. | Other Tests.   | Usual Appearance.  |
|---|-------------|--|--|
| O. Talc, p. 545, $H_2Mg_3(SiO_3)_4$<br>H., 1 to 1.5 Sp. gr., 2.5 to 2.9                     | 5 to 5.5    | Pink with Co. Sol.<br>Soapy feeling                                | White greenish or gray foliated compact and fibrous            |
| — Pyrophyllite, p. 548,<br>$HA_2(SiO_3)_2$<br>H., 1 to 2 Sp. gr., 2.8 to 2.9                | 6           | Blue with Co. Sol.   | Radiated foliæ or fibres and compact masses                    |
| Chlorite Group, p. 541,<br>H., 1 to 2.5 Sp. gr., 2.6 to 2.9                                 | 5 to 5.5    | Much water in closed tube.<br>Cleave to non-elastic plates         | Dark green, rarely red, coarse and fine scales and crystals    |
| Mica Group, p. 537,<br>H., 2 to 3 Sp. gr., 2.7 to 3   | 4 to 5      | Water at high heat closed tube.<br>Cleave to elastic plates        | Black, amber, gray, etc., scales and pseudo-hexagonal crystals |
| M. Orthoclase, p. 492,<br>(or Microcline), $KAlSi_3O_8$<br>H., 6 to 6.5 Sp. gr., 2.5 to 2.6 | 5           | Violet flame (color screen). Cleavage $90^\circ$ . Rarely striated | Flesh red, white, gray, etc. Cleavages and crystals common     |
| O. Enstatite-Hypersthene, p. 504,<br>(Mg.Fe) $SiO_3$<br>H., 5.5 Sp. gr., 3.1 to 3.3         | 5 to 6      |  | Gray, brown, black lamellar to fibrous, pearly metalloidal     |
| O. Anthophyllite, p. 507,<br>(MgFe) $SiO_3$<br>H., 5.5 to 6 Sp. gr., 3.1 to 3.2             | 5 to 6      | After fusion is magnetic   | Gray to green lamellar and fibrous                             |
| H. Tourmaline, p. 524,<br>$R_3B_3(SiO_3)_4$<br>H., 7 to 7.5 Sp. gr., 3 to 3.2               | 5           | Green Fl. with Bo. Fl. After fusion will gelatinize                | Red, blue, colorless, etc., prisms often triangular            |
| H. Beryl, p. 522, $Be_3Al_2(SiO_3)_6$<br>H., 7.5 to 8 Sp. gr., 2.6 to 2.8                   | 5 to 5.5    | Often white on fusion  | Green, yellow, blue, hexagonal prisms. Also columnar           |

## 52. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.            | Interference Color.            | Other Notable Characters.   | Name.                          |
|---------------------------------|--------------------------------|---|--------------------------------|
| < Bromoform                     | Abnormal blue or brown or gray | Plates. Biax. I. F. Green. Pleochroic                                       | Chlorite Group<br>See page 542 |
|                                 | Gray or White                  | Irregular   | Beryl                          |
|                                 | Gray or White to Bright A.     | Laths. Ex.,    on 001, $5^\circ$ on 010                                     | Orthoclase                     |
|                                 | Gray or White to Bright A.     | Laths. Ex., $15^\circ$ on 001, $5^\circ$ on 010. Crossed twinning (grating) | Microcline                     |
|                                 | Bright A.                      | Irregular, or plates. Biax. I. F.   | Talc                           |
|                                 | Gray or White to Bright A.     | Laths. Ex.,   , El. (+)   | Pyrophyllite                   |
| > Bromoform                     | Gray or White or Black         | Plates. Biax. I. F. Distinctions p. —                                       | Mica Group                     |
| < $\alpha$ -Monobrom-Naphthalin | Gray or White to Bright A.     | Irregular. Pleochroic and colorless   | Tourmaline                     |
| > $\alpha$ -Monobrom-Naphthalin | Gray or White to Bright A.     | Laths and fibres. Ex.,   . El. (+). Colorless                               | Enstatite                      |
|                                 |                                | Laths. Ex.,   , El. (+). Pleochroic pink to green                           | Hypersthene                    |
|                                 | Bright B.                      | Fibres. Ex.   . El. (+)   | Anthophyllite                  |



### 53. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.                                | Closed Tube. | Other Tests.         | Usual Appearance.                       |
|--|--------------|----------------------|---|
| —, Allophane, 549.<br>$\text{Al}_2\text{SiO}_5 \cdot 5\text{H}_2\text{O}$<br>H., 3 Sp. gr., 1.88 | Much water   | Crumbles when heated | Sky blue, green, brown and white crusts |

### 54. A.

|  |                              |  |   |
|--|------------------------------|--|---|
| M. Aluminite, p. 415.<br>$\text{Al}_2\text{SO}_4 + 9\text{H}_2\text{O}$<br>H., 1 to 2 Sp. gr., 1.6                   | Much water.<br>$\text{SO}_2$ | Infusible with soda but mass will stain silver | White chalky with harsh feel                  |
| —, Bauxite, p. 413, $\text{Al}_2\text{O}(\text{OH})_3$<br>H., 1 to 3 Sp. gr., 2.4 to 2.5                             | Water at high heat           | May become magnetic in R. F.                   | Rounded grains or earthy or clay-like         |
| I. Leucite, p. 498, $\text{KAl}(\text{SiO}_3)_2$<br>H., 5.5 to 6 Sp. gr., 2.4 to 2.5                                 | Acid water etches            | Violet Fl. (Color screen)                      | Translucent white, nearly spherical           |
| O. Wavellite, p. 471,<br>$\text{Al}_3(\text{OH})_4(\text{PO}_4)_4 + 9\text{H}_2\text{O}$<br>H., 3 to 4 Sp. gr., 2.33 |                              |  | Spheres and hemispheres of radiating crystals |

### 54. B. (CRUSHED FRAGMENTS.)

| Index of Refraction. | Interference Color.                     | Other Notable Characters.                     | Name.           |
|----------------------|---|---|-----------------|
| < Xylol              | Gray or White                           | Fibres. Ex., Obl.                             | Aluminite       |
| > Xylol              | Black aggregate Gray or White or Black. | Irregular Irregular. Twin lamellae inclusions | Bauxite Leucite |
| < Bromoform          | Bright B.                               | Rectangles and needles. Ex.,   . El. (+)      | Wavellite       |

### 55. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.  | Closed Tube.         | Other Tests.                    | Usual Appearance.                               |
|--|----------------------|---------------------------------|---|
| M. Kaolin, p. 547, $\text{H}_2\text{Al}_2\text{Si}_2\text{O}_5$<br>H., 2 to 2.5 Sp. gr., 2.6                               | Water                | Usually plastic                 | Dull white, mealy unctuous                      |
| M. Gibbsite, p. 415, $\text{Al}(\text{OH})_3$<br>H., 2.5 to 3.5 Sp. gr., 2.4   | Water                | Exfoliates                      | Smooth pearly crusts or fibres                  |
| H. Alunite, p. 416,<br>$\text{K}(\text{AlO}_3)(\text{SO}_4)_2 + 3\text{H}_2\text{O}$<br>H., 3.5 to 4.5 Sp. gr., 2.6 to 2.7 | Water at red heat    | Violet Fl.                      | Cub ids or granular or fibrous. White or tinted |
| Tri. Cyanite, p. 519, $\text{Al}_2\text{SiO}_5$<br>H., 5 to 7 Sp. gr., 3.6 to 3.7  |                      | Softer parallel length          | Blue blade-like. Centre bluest                  |
| O. Sillimanite, p. 519, $\text{Al}_2\text{SiO}_5$<br>H., 6 to 7 Sp. gr., 3.2   |                      | Very tough                      | Thin gray or brown crystals or fibrous          |
| O. Andalusite, p. 518, $\text{Al}_2\text{SiO}_5$<br>H., 7 to 7.5 Sp. gr., 3.1 to 3.2                                       |                      | Inclusions. See p. 80           | Gray or pink nearly square prisms               |
| H. Phenacite, p. 567, $\text{Be}_2\text{SiO}_4$<br>H., 7.5 to 8 Sp. gr., 2.96  |                      | Resembles quartz                | Colorless rhombohedral crystals                 |
| O. Diaspore, p. 415, $\text{AlO}(\text{OH})$<br>H., 6.5  | Water                |                                 | Pink or brown foliated                          |
| O. Topaz, p. 523, $\text{Al}_2\text{SiO}_5\text{F}_{10}$<br>H., 8 Sp. gr., 3.4 to 3.6                                      | O. T. F. with S. Ph. | Easy basal cleavage             | Colorless, yellow and bluish crystals. Columnar |
| I. Spinel, p. 558, $\text{MgAl}_2\text{O}_4$<br>H., 8 Sp. gr., 3.5 to 4.5  |                      | Completely soluble S. Ph.       | Red, black, etc., octahedra                     |
| O. Chrysoberyl, 560, $\text{BeAl}_2\text{O}_4$<br>H., 8.5 Sp. gr., 3.5 to 3.8  |                      | Tabular and twinned             | Pale to deep green crystals                     |
| H. Corundum, p. 412, $\text{Al}_2\text{O}_3$<br>H., 9 Sp. gr., 3.9 to 4.1  |                      | Nearly cubic parting striations | Gray, blue, red, etc. crystals                  |

| 55. B. (CRUSHED FRAGMENTS.)                               |  |  | Name.                                 |
|---|--|--|---------------------------------------|
| Index of Refraction.                                      | Interference Color.                                      | Other Notable Characters.  |                                       |
| < Bromoform   | Gray or White. Aggregate                                 | Irregular and plates. Cloudy   | <b>Kaolinite</b>                      |
|   | Gray or White. Aggregate                                 | Plates   | <b>Gibbsite</b>                       |
|   | Gray or White or Black                                   | Three or six-sided with Uniax. I. F. or irregular                          | <b>Alunite</b>                        |
| > Bromoform<br>< $\alpha$ -Monobrom-Naphthalin            | Gray or White<br>Gray or White to Bright A.              | Plates with Biax. I. F. and irregular<br>Irregular or laths with Ex.       | <b>Topaz</b><br><b>Andalusite</b>     |
| > $\alpha$ -Monobrom-Naphthalin<br><br>< Methylene Iodide | Black  | Irregular. Tinted green or brown   | <b>Spinel</b>                         |
|   | Gray or White to Bright A.                               | Irregular  | <b>Phenacite</b>                      |
|   | Gray or White to Bright A.                               | Laths. Cross cracks. Ex. 30°. El. (+)<br>Laths or Needles. Ex.   . El. (+) | <b>Cyanite</b><br><b>Sillimanite</b>  |
| > Methylene Iodide  | Bright B.  | Laths. Ex.   . El. (—).  | <b>Diaspore</b>                       |
|   | Gray or White to Bright A.<br>Gray or White to Bright A. | Irregular, green or colorless<br>Irregular                                 | <b>Chrysoberyl</b><br><b>Corundum</b> |

## 56. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.                             | Fragments in HCl.   | With Cobalt Solution.       | Usual Appearance.                                      |
|---|---------------------|-----------------------------|--|
| H. <b>Calcite</b> , p. 446, $\text{CaCO}_3$<br>H., 3 Sp. gr., 2.7                             | Rapid eff. cold     | Unchanged on <i>boiling</i> | White, yellowish, etc., crystals and granular (marble) |
| O. <b>Aragonite</b> , p. 444, $\text{CaCO}_3$<br>H., 3.5 to 4 Sp. gr., 2.9                    | Rapid eff. cold     | Lilac on <i>boiling</i>     | White, yellowish, prisms, needles, fibres coral-like   |
| H. <b>Dolomite</b> , p. 448, $\text{CaMg}(\text{CO}_3)_2$<br>H., 3.5 to 4 Sp. gr., 2.8 to 2.9 | Slow eff. cold      | Pink on <i>ignition</i>     | White or pink curved rhombohedrons, granular           |
| H. <b>Magnesite</b> , p. 453, $\text{MgCO}_3$<br>H., 3.5 to 4.5 Sp. gr., 3 to 3.1             | Very slow eff. cold | Pink on <i>ignition</i>     | White nodules shell-like fracture also cleavable       |
| H. <b>Rhodochrosite</b> , p. 284, $\text{MnCO}_3$<br>H., 4.5 Sp. gr., 3.5 to 4.5              | Very slow eff. cold | Unaffected                  | Pink to red curved rhombohedrons or massive            |

## 56. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.*           | Interference Color. | Other Notable Characters.                     | Name.                |
|---------------------------------|---------------------|---|----------------------|
| < $\alpha$ -Monobrom-Naphthalin | High Order          | Plates or laths. Ex.   . El. (—)              | <b>Aragonite</b>     |
|                                 | High Order          | Rhombs. Striations    long diagonal. Ex. Sym. | <b>Calcite</b>       |
| > $\alpha$ -Monobrom-Naphthalin | High Order          | Rhombs. Ex. Sym.                              | <b>Dolomite</b>      |
|                                 | High Order          | Rhombs. Ex. Sym.                              | <b>Magnesite</b>     |
|                                 | High Order          | Rhombs. Ex. Sym.                              | <b>Rhodochrosite</b> |

\* All except aragonite cleave to rhombohedrons of  $105^\circ$  to  $107^\circ$ .

\* These are parallel short diagonal. The indices parallel the long diagonal are notably larger by 0.17 to 0.22.

## 57. A.

| Crystal System: Name, Composition, Hardness, and Specific Gravity.                                 | Closed Tube. | Other Tests.   | Appearance.  |
|--|--------------|--|--|
| Cerite, p. 351, Ce., etc., Si.<br>H., 5-5 Sp. gr., 4.9   | Water        | In forceps. Yellow<br>In borax dark yellow O. F. hot | Brown to cherry red massive. Resinous                  |
| T. Thorite, p. 315, ThSiO <sub>4</sub><br>H., 5 Sp. gr., 4.8 to 5.2                                | Water        | High sp. gr. Usually altered                         | Orange to brown, zircon shaped                         |
| O. Chrysolite, p. 513,<br>(MgFe) <sub>2</sub> SiO <sub>4</sub><br>H., 6.5 to 7 Sp. gr., 3.3 to 3.6 | Whitens      | In forceps whitens                                   | Olive to gray green glassy grains and masses of grains |
| O. Forsterite, p. 513, Mg <sub>2</sub> SiO <sub>4</sub><br>H., 6 to 7 Sp. gr., 3.2 to 3.3          | Whitens      |  | White or yellow grains or crystals                     |

## 58. A.

|  |   |  |   |
|--|---|--|---|
| Garnierite, p. 294,<br>H <sub>2</sub> (Ni. Mg)SiO <sub>4</sub> + H <sub>2</sub> O<br>H., 2 to 3 Sp. gr., 2.3 to 2.8      | Blackens.<br>Yields water   | Borax O. F. violet hot, brown cold                   | Emerald- and pale-green and cellular masses and crusts. |
| — Chrysocolla, p. 372,<br>CuSiO <sub>3</sub> · 2H <sub>2</sub> O<br>H., 2 to 4 Sp. gr., 2 to 2.3                         | Blackens.<br>Yields water   | With soda on coal a copper button. Emerald green Fl. | Enamel-like crusts, veins or compact                    |
| H. Brucite, p. 452, Mg(OH) <sub>2</sub><br>H., 2.5 Sp. gr., 2.4  | Water   | Pink with Co. Sol.                                   | White foliated or fibrous. Pearly                       |
| O. Cervantite, p. 335, Sb <sub>2</sub> O <sub>4</sub><br>H., 4 to 5 Sp. gr., 4.1   |   | Easily reduced on charcoal                           | Yellow to white dull or pearly                          |
| M. Monazite, p. 313,<br>(Ce. La. Di)PO <sub>4</sub><br>H., 5 to 5.5 Sp. gr., 4.9 to 5.3                                  | Reflected light with spectro-scope gives broad line between the red and yellow and narrow line in the green |  | Resinous brown crystals or yellow grains                |
| Turquoise, p. 570,<br>Al <sub>2</sub> (OH) <sub>2</sub> PO <sub>4</sub> H <sub>2</sub> O<br>H., 6 Sp. gr., 2.6 to 2.8    | Blackens.<br>Yields water   | P test see p. 191. Blue Fl. with HCl                 | Sky-blue to green nearly opaque with lustre of wax      |
| M. Gadolinite, p. 315,<br>Yt <sub>2</sub> Be <sub>2</sub> FeSi <sub>2</sub> O <sub>10</sub><br>H., 6.5 to 7 Sp. gr., 4.3 | Unaltered   | Swells, cracks and often glows                       | Rough green to black prisms                             |

## 57. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.    | Interference Color.    | Other Notable Characters.                            | Name.                    |
|-------------------------|------------------------|--|--------------------------|
| < α-Monobrom-Naphthalin | Bright A.              | Irregular. Colorless or pleochroic yellow            | Chondrodite              |
| > α-Monobrom-Naphthalin | Bright B.<br>Bright B. | Irregular, colorless, yellow<br>Irregular. Colorless | Chrysolite<br>Forsterite |
| > Methylene Iodide      | Black                  | Often isotropic                                      | Thorite                  |

## 58. B. (CRUSHED FRAGMENTS.)

|                    |  |   |                        |
|--------------------|--|---|------------------------|
| < Bromoform        | Black or Gray or White<br>Black or Aggregate | Plates, Uniax. I. F. Fibres, Ex.   . El. (—)<br>Irregular. Pale blue or green | Brucite<br>Chrysocolla |
| = Bromoform        | Gray or White Aggregate                      | Irregular. Greenish   | Garnierite             |
| > Bromoform        | Gray or White Aggregate<br>Bright B.         | Irregular<br>Plates. Faint yellow   | Turquoise<br>Monazite  |
| > Methylene Iodide | Varies Black to high order                   | Normally anisotropic, often isotropic   | Gadolinite             |

## 59. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.   | Other Tests.  | Usual Appearance.  |
|---|---|--|
| T. Xenotime, p. 313, $\text{YPO}_4$<br>H., 4 to 5 Sp. gr., 4.5  | Test P. p. 191  | Zircon-like crystals, brown or yellow in color   |
| T. Fergusonite, p. 356,<br>Cb, $\text{TaYCe}$ , etc.<br>H., 5.5 to 6 Sp. gr., 5.8                               | Test Cb p. 186  | Brownish black resinous  |
| — Opal, p. 487, $\text{SiO}_2 \cdot \text{H}_2\text{O}$<br>H., 5.5 to 6.5 Sp. gr., 2.1 to 2.2                   | In closed tube. A little water becomes opaque<br>Rarely play of colors<br>S. Ph. O. F. yellow, made violet R. F.<br>No crystals | No crystals. Translucent. May be any color, opaque and dull<br>Brownish red to black hairs to coarse crystals<br>"Tendon" colored, red, bluish, etc. Lustre wax-like |
| T. Rutile, p. 309, $\text{TiO}_2$<br>H., 6 to 6.5 Sp. gr., 4.1 to 4.2   | Horizontal striations on prisms   | Prisms with rhombohedra. Also massive. Colorless and all colors  |
| Chalcedony, p. 486, $\text{SiO}_2$<br>H., 6.5 Sp. gr., 2.6  |   | Minute tabular and twinned crystals  |
| H. Quartz, p. 484, $\text{SiO}_2$<br>H., 7 Sp. gr., 2.65  |   | Emerald green, dodecahedrons   |
| H. Tridymite, p. 486, $\text{SiO}_2$<br>H., 7 Sp. gr., 2.3  | Green bead with S. Ph.  |  |
| I. Garnet, p. 510, Uvarovite, $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$<br>H., 7.5 Sp. gr., 3.1 to 4.3           | Glows intensely on heating. Adamantine lustre   | Sharp square pyramid and prism brown, gray, red, etc. Also pebbles   |
| T. Zircon, p. 314, $\text{ZrSiO}_4$<br>H., 7.5 Sp. gr., 4.7   |   | Dark brown, usually twinned (cross) prisms at $90^\circ$ and $120^\circ$   |
| O. Staurolite, p. 520,<br>$\text{Fe}(\text{AlO})_4(\text{AlOH})(\text{SiO}_4)$<br>H., 7.5 Sp. gr., 3.6 to 3.7   | Green flame with $\text{KHSO}_4$ $\text{CaF}_2$   | Transparent deep red prisms  |
| H. Tourmaline, p. 524,<br>(Rubellite) $\text{Rb}_3\text{B}_3(\text{SiO}_3)_4$<br>H., 7 to 7.5 Sp. gr., 3 to 3.2 | In powder is burned to $\text{CO}_2$ . Cleavages at $70^\circ$ $31'$ .  | Colorless and tinted octahedra with rounded edges. Lustre like oiled glass   |
| I. Diamond, p. 550, C<br>H., 10 Sp. gr., 3.51   |   |  |

| 59. B. (CRUSHED FRAGMENTS.)                    |  |   | Name.   |
|--|--|---|---|
| Index of Refraction.                           | Interference Color.                                      | Other Notable Characters.   |   |
| < Xylol  | Black<br>Gray or White                                   | Irregular<br>Plates. Twinned  | Opal<br>Tridymite   |
| > Xylol<br>< Bromoform                         | Gray or White to Bright A.<br>Gray or White to Bright A. | Irregular<br>Irregular. Fibrous with crossed Nicols                       | Quartz<br>Chalcedony  |
| > Bromoform<br>< $\alpha$ -Monobrom-Naphthalin | Gray or White to Bright A.                               | Irregular. Red, pleochroic  | Tourmaline,<br>(Rubellite)  |
| = Methylene Iodide                             | Gray or White  | Irregular. Pleochroic. Inclusions   | Staurolite  |
| > Methylene Iodide                             | Black<br>Black<br>Bright B.<br>High Order<br>High Order  | Irregular. Pink<br>Irregular<br>Irregular<br>Irregular. Yellow to reddish | Garnet,<br>(Uvarovite)<br>Diamond<br>Zircon<br>Xenotime<br>Rutile |

## 57. A.

| Crystal System: Name, Composition, Hardness, and Specific Gravity.                                 | Closed Tube. | Other Tests.   | Appearance.  |
|--|--------------|--|--|
| Cerite, p. 351, Ce., etc., Si.<br>H., 5.5 Sp. gr., 4.9   | Water        | In forceps. Yellow<br>In borax dark yellow O. F. hot | Brown to cherry red massive. Resinous                  |
| T. Thorite, p. 315, ThSiO <sub>4</sub><br>H., 5 Sp. gr., 4.8 to 5.2                                | Water        | High sp. gr. Usually altered                         | Orange to brown, zircon shaped                         |
| O. Chrysolite, p. 513,<br>(MgFe) <sub>2</sub> SiO <sub>4</sub><br>H., 6.5 to 7 Sp. gr., 3.3 to 3.6 | Whitens      | In forceps whitens                                   | Olive to gray green glassy grains and masses of grains |
| O. Forsterite, p. 513, Mg <sub>2</sub> SiO <sub>4</sub><br>H., 6 to 7 Sp. gr., 3.2 to 3.3          | Whitens      |  | White or yellow grains or crystals                     |

## 58. A.

|   |   |  |   |
|---|---|--|---|
| Garnierite, p. 294,<br>H <sub>2</sub> (Ni. Mg)SiO <sub>4</sub> + H <sub>2</sub> O<br>H., 2 to 3 Sp. gr., 2.3 to 2.8     | Blackens.<br>Yields water   | Borax O. F. violet hot, brown cold                   | Emerald- and pale-green and cellular masses and crusts. |
| — Chrysocolite, p. 372,<br>CuSiO <sub>3</sub> · 2H <sub>2</sub> O<br>H., 2 to 4 Sp. gr., 2 to 2.3                       | Blackens.<br>Yields water   | With soda on coal a copper button. Emerald green Fl. | Enamel-like crusts, veins or compact                    |
| H. Brucite, p. 452, Mg(OH) <sub>2</sub><br>H., 2.5 Sp. gr., 2.4   | Water   | Pink with Co. Sol.                                   | White foliated or fibrous. Pearly                       |
| O. Cervantite, p. 335, Sb <sub>2</sub> O <sub>4</sub><br>H., 4 to 5 Sp. gr., 4.1  |   | Easily reduced on charcoal                           | Yellow to white dull or pearly                          |
| M. Monazite, p. 313,<br>(Ce. La. Di)PO <sub>4</sub><br>H., 5 to 5.5 Sp. gr., 4.9 to 5.3                                 | Reflected light with spectro-scope gives broad line between the red and yellow and narrow line in the green |  | Resinous brown crystals or yellow grains                |
| Turquoise, p. 570,<br>Al <sub>2</sub> (OH) <sub>2</sub> PO <sub>4</sub> · H <sub>2</sub> O<br>H., 6 Sp. gr., 2.6 to 2.8 | Blackens.<br>Yields water   | P test see p. 191. Blue Fl. with HCl                 | Sky-blue to green nearly opaque with lustre of wax      |
| M. Gadolinite, p. 315,<br>Y <sub>2</sub> Ba <sub>2</sub> FeSi <sub>2</sub> O <sub>10</sub><br>H., 6.5 to 7 Sp. gr., 4.3 | Unaltered   | Swells, cracks and often glows                       | Rough green to black prisms                             |

## 57. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.    | Interference Color.    | Other Notable Characters.                            | Name.                    |
|-------------------------|------------------------|--|--------------------------|
| < α-Monobrom-Naphthalin | Bright A.              | Irregular. Colorless or pleochroic yellow            | Chondrodite              |
| > α-Monobrom-Naphthalin | Bright B.<br>Bright B. | Irregular, colorless, yellow<br>Irregular. Colorless | Chrysolite<br>Forsterite |
| > Methylene Iodide      | Black                  | Often isotropic                                      | Thorite                  |

## 58. B. (CRUSHED FRAGMENTS.)

|                    |   |   |                         |
|--------------------|---|---|-------------------------|
| < Bromoform        | Black or Gray or White<br>Black or Ag-gregate | Plates, Uniax. I. F. Fibres, Ex.   . El. (—)<br>Irregular. Pale blue or green | Brucite<br>Chrysocolite |
| = Bromoform        | Gray or White Aggregate                       | Irregular. Greenish   | Garnierite              |
| > Bromoform        | Gray or White Aggregate<br>Bright B.          | Irregular<br>Plates. Faint yellow   | Turquoise<br>Monazite   |
| > Methylene Iodide | Varies Black to high order                    | Normally anisotropic, often isotropic   | Gadolinite              |

## 59. A.

| Crystal System: Name, Composition, Hardness and Specific Gravity.   | Other Tests.   | Usual Appearance.   |
|---|--|---|
| T. Xenotime, p. 313, $\text{YPO}_4$<br>H., 4 to 5 Sp. gr., 4.5<br>T. Fergusonite, p. 356,<br>Cb, $\text{TaYCe}$ , etc.<br>H., 5.5 to 6 Sp. gr., 5.8<br>— Opal, p. 487, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$<br>H., 5.5 to 6.5 Sp. gr., 2.1 to 2.2                         | Test P. p. 191<br>Test Cb p. 186<br><br>In closed tube. A little water becomes opaque. Rarely play of colors<br>S. Ph. O. F. yellow, made violet R. F.<br>No crystals<br><br>Horizontal striations on prisms | Zircon-like crystals, brown or yellow in color<br>Brownish black resinous<br><br>No crystals. Translucent. May be any color, opaque and dull<br>Brownish red to black hairs to coarse crystals<br>"Tendon" colored, red, bluish, etc. Lustre wax-like<br>Prisms with rhombohedra. Also massive. Colorless and all colors<br>Minute tabular and twinned crystals<br>Emerald green, dodecahedrons |
| T. Rutile, p. 309, $\text{TiO}_2$<br>H., 6 to 6.5 Sp. gr., 4.1 to 4.2<br>Chalcedony, p. 486, $\text{SiO}_2$<br>H., 6.5 Sp. gr., 2.6<br>H. Quartz, p. 484, $\text{SiO}_2$<br>H., 7 Sp. gr., 2.65   | Green bead with S. Ph.<br><br>Glows intensely on heating. Adamantine lustre<br><br>Green flame with $\text{KHSO}_4$ $\text{CaF}_2$   | Sharp square pyramid and prism brown, gray, red, etc. Also pebbles<br>Dark brown, usually twinned (cross) prisms at $90^\circ$ and $120^\circ$<br>Transparent deep red prisms   |
| H. Tridymite, p. 486, $\text{SiO}_2$<br>H., 7 Sp. gr., 2.3<br>I. Garnet, p. 510, Uvarovite, $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$<br>H., 7.5 Sp. gr., 3.1 to 4.3<br>T. Zircon, p. 314, $\text{ZrSiO}_4$<br>H., 7.5 Sp. gr., 4.7  | In powder is burned to $\text{CO}_2$ . Cleavages at $70^\circ 31'$ .   | Colorless and tinted octahedra with rounded edges. Lustre like oiled glass  |
| O. Staurolite, p. 520, $\text{Fe}(\text{AlO})_4(\text{AlOH})(\text{SiO}_4)$<br>H., 7.5 Sp. gr., 3.6 to 3.7<br>H. Tourmaline, p. 524, (Rubellite) $\text{R}_{11}\text{B}_3(\text{SiO}_4)_4$<br>H., 7 to 7.5 Sp. gr., 3 to 3.2<br>I. Diamond, p. 550, C<br>H., 10 Sp. gr., 3.51 |  |   |

## 59. B. (CRUSHED FRAGMENTS.)

| Index of Refraction.                           | Interference Color.                                      | Other Notable Characters.   | Name.   |
|--|--|---|---|
| < Xylol  | Black<br>Gray or White                                   | Irregular<br>Plates. Twinned  | Opal<br>Tridymite   |
| > Xylol<br>< Bromoform                         | Gray or White to Bright A.<br>Gray or White to Bright A. | Irregular<br>Irregular. Fibrous with crossed Nicols                       | Quartz<br>Chalcedony  |
| > Bromoform<br>< $\alpha$ -Monobrom-Naphthalin | Gray or White to Bright A.                               | Irregular. Red, pleochroic  | Tourmaline,<br>(Rubellite)  |
| = Methylene Iodide                             | Gray or White  | Irregular. Pleochroic. Inclusions   | Staurolite  |
| > Methylene Iodide                             | Black<br>Black<br>Bright B.<br>High Order<br>High Order  | Irregular. Pink<br>Irregular<br>Irregular<br>Irregular. Yellow to reddish | Garnet,<br>(Uvarovite)<br>Diamond<br>Zircon<br>Xenotime<br>Rutile |

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